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THESIS

ASSESSING THE EFFECTIVENESS OF THE BATTLEFIELD COMBAT IDENTIFICATION SYSTEM

by

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June 1999

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The Battlefield Combat Identification System (BCIS) was developed at the direction of the Joint Chiefs of Staff following the Gulf War to address the problem of direct fire fratricide. The system is designed to improve target identification and increase situational awareness for ground combat forces. The purpose of this thesis is to determine whether BCIS improves combat effectiveness. Additionally, this thesis provides a simulation tool that is utilized to assess the effectiveness of BCIS variants. The experiment involves a simulation executed in Simkit simulating an M1A1 tank company performing two doctrinal missions (defense and movement to contact) under three different cases: without BCIS, with BCIS equipped for target identification only, and with BCIS equipped with a digital data link. The measures of performance are the loss exchange ratio as a measure of lethality and the fratricide ratio as a measure of fratricide incidents. Results of the analysis indicate that BCIS does improve combat effectiveness. Specifically, BCIS increases lethality and reduces fratricide over non BCIS equipped units. BCIS equipped with a digital data link did not provide an increase over baseline BCIS.

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ASSESSING THE EFFECTIVENESS OF THE BATTLEFIELD COMBAT IDENTIFICATION SYSTEM

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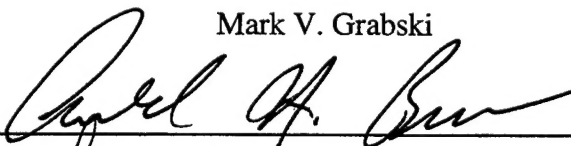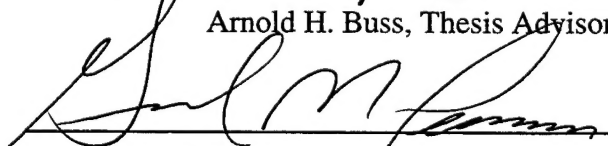
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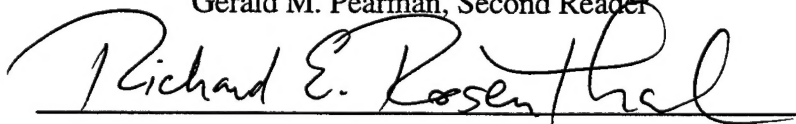**June 1999**

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iii

ABSTRACT

The Battlefield Combat Identification System (BCIS) was developed at the direction of the Joint Chiefs of Staff following the Gulf War to address the problem of direct fire fratricide. The system is designed to improve target identification and increase situational awareness for ground combat forces. The purpose of this thesis is to determine whether BCIS improves combat effectiveness. Additionally, this thesis provides a simulation tool that is utilized to assess the effectiveness of BCIS variants. The experiment involves a simulation executed in Simkit simulating an M1A1 tank company performing two doctrinal missions (defense and movement to contact) under three different cases: without BCIS, with BCIS equipped for target identification only, and with BCIS equipped with a digital data link. The measures of performance are the loss exchange ratio as a measure of lethality and the fratricide ratio as a measure of fratricide incidents. Results of the analysis indicate that BCIS does improve combat effectiveness. Specifically, BCIS increases lethality and reduces fratricide over non BCIS equipped units. BCIS equipped with a digital data link did not provide an increase over baseline BCIS.

DISCLAIMER

The reader is cautioned that computer programs developed in this research were not tested for all possible cases. While every effort was made to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional validation is at the risk of the user.

TABLE OF CONTENTS

LIST OF FIGURES

x

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

AMC	Army Material Command
AMSAA	Army Material Systems Analysis Agency
APC	Armored Personnel Carrier
ARI	Army Research Institute
ATR	Automatic Target Recognition
BCIS	Battlefield Combat Identification System
CALL	Center For Army Lessons Learned
CI	Combat Identification
DDL	Digital Data Link
DVO	Direct View Optics
EPLRS	Enhanced Position, Location and Reporting System
FLIR	Forward Looking Infrared
I2	Image Intensifiers
ID	Identification
IFV	Infantry Fighting Vehicle
IR	Infrared Sensors
METT-T	Mission, Enemy, Terrain, Troops & Equipment, Time
mmW	Millimeter Wave
MRC	Minimum Resolvable Contrast
MRT	Minimum Resolvable Temperature
NPS	Naval Postgraduate School
NRT	Near Real Time
RF	Radio Frequency
SA	Situational Awareness
TI	Target Identification
TRADOC	Training and Doctrine Command

EXECUTIVE SUMMARY

The Battlefield Combat Identification System (BCIS) was developed at the direction of the Joint Chiefs of Staff following the Gulf War to address the problem of direct fire fratricide. An alarming number of US casualties during the war were the result of friendly fire. BCIS was developed as one of the solutions to the fratricide problem. The system is designed to improve target identification by conducting an electronic query of a potential target vehicle. This query is done prior to engaging the vehicle with direct fire and at extended ranges where visual identification is not possible. Other BCIS variants increase situational awareness for ground combat forces by sharing the results of these queries with other systems in the data net.

The purpose of this thesis is to determine whether BCIS improves combat effectiveness. Combat effectiveness is evaluated using two measures of performance: the loss exchange ratio measures lethality and the fratricide ratio measures fratricide reduction. To determine whether BCIS improves combat effectiveness, the thesis develops a simulation that models the conduct of fire process and the methods used by the BCIS variants to identify targets. Utilizing approved algorithms and methods the BCIS simulation model provides a tool to analyze BCIS variants. The simulation is executed in Simkit simulating an M1A1 tank company performing two doctrinal missions (defense and movement to contact) under three different cases: without BCIS, with BCIS equipped for target identification only, and with BCIS equipped with a digital data link (BCIS DDL).

Results of the simulation model indicate that BCIS does increase the combat effectiveness of a tank company. Specifically, BCIS equipped units have increased lethality and have fewer fratricide incidents than non-BCIS equipped units. Units equipped with BCIS DDL did not show an increase in combat effectiveness over units equipped with baseline BCIS but did provide an increase in overall combat effectiveness over non BCIS equipped forces. Also, the thesis research provides insight to effective means of modeling BCIS and a tool for further BCIS analysis.

Conclusions from this research are that identification and situational awareness systems such as BCIS reduce the tradeoff between engaging targets at extended ranges and the ability to correctly identify targets. Units should be equipped with BCIS since they will be more lethal and less likely to commit fratricide than non BCIS equipped units. Further research is required to determine the best implementation of the impact of situational awareness, BCIS DDL, on human decision making, and how situational awareness systems improve combat effectiveness.

I. INTRODUCTION

"Fratricide is the employment of friendly weapons and munitions with the intent to kill the enemy or destroy his equipment or facilities, which results in unforeseen and unintentional death or injury to friendly personnel." - TRADOC Fratricide Action Plan [Ref. 1:p. 3]

The modern battlefield is more lethal than any in history. Operational tempo is rapid and the nonlinear nature of the battlefield creates command and control challenges for leaders at all levels. The accuracy and lethality of modern weapons make it possible to engage and destroy targets at extended ranges. At the same time, however, sophisticated sighting systems enable target acquisition at ranges often exceeding our ability to accurately identify targets as friend or foe, increasing the potential for fratricide. As a result, the Army is taking steps to reduce the number of fratricide incidents by developing systems to aid in target identification.

A.   FRATRICIDE STUDIES

During Operation Desert Storm, fratricide accounted for a sobering 17% of the Army's 615 casualties. Of the 15 different fratricide incidents involving Army units, 12 resulted from direct fire engagements, 11of which occurred at night. The decision to fire was based largely upon the gunner's knowledge of his location and the location of other friendly forces with respect to a given target. [Ref. 1:p. 4]

Because of the increasing awareness of fratricide, the Army's Combat Training Centers (CTCs) have tracked incidents involving fratricide for the last ten years. The

1

data from the CTCs provide better insight into the causes and results of fratricide than data from recent conflicts. For each of the battles conducted at the CTCs, detailed records on both friendly and enemy forces are kept that allow for future study. A study conducted by the Center for Army Lessons Learned (CALL) and the Army Research Institute (ARI) used CTC data from 1986 to 1990 to examine rates of fratricide. A sample from the CTC data indicated that about 11% of all attempted direct fire engagements were fratricidal in nature.

The CTC study had several conclusions. First, the likelihood of fratricide is much lower during defensive operations than offensive operations. Deliberate attacks produced the highest incidents of fratricide risk. Despite thorough preparation, the massing of units and firepower during a deliberate attack increases the overall risks of fratricide. This can primarily be attributed to the confusion of close combat and the speed at which close combat events take place, resulting in degraded situational awareness. The number of engagements beyond 2000 meters is a small proportion of the total number of engagements, but the proportion of fratricide engagements at ranges beyond 2000 meters was greater than the proportion of fratricide incidents less than 2000 meters. The study fails to report the magnitude of the difference in proportions but expresses concern about identifying targets at extended ranges. The higher rate of fratricide can be attributed to increased difficulty of identification at longer ranges. [Ref. 1:p. 6]

Direct fire fratricide will only be compounded as the lethality of future weapons systems increases. One of the tenets of Army Vision 2010, Precision Engagement, calls for the use of increased lethality at extended ranges to allow the commander to destroy

enemy capabilities early and help shape the battlespace for friendly freedom of action. [Ref. 2] The ability to use precision systems and munitions to accomplish these tenents requires both doctrinal and technological solutions to resolve fratricide issues.

B. CAUSES OF FRATRICIDE

Immediately following the Persian Gulf War, General Gordon R. Sullivan, then Vice Chief of Staff and later Army Chief of Staff, directed the Army's Training and Doctrine Command (TRADOC) and the Army Material Command (AMC) to examine the causes and potential solutions to fratricide. The task force identified three main causes of fratricide: poor situational awareness, target identification, and weapons systems failures [Ref. 3:p. 2].

Situational awareness is the real-time accurate knowledge of one's own location and orientation, location of friendly forces, enemy forces, and noncombatants [Ref. 4:p. 2]. Several factors contribute to situational awareness failures but only three were modeled in this thesis. First, inadequate fire and maneuver control measures may contribute to fratricide incidents. Units can inadvertently maneuver into another friendly unit's sector or fire across a friendly sector boundary. This places both units at a high risk for fratricide. Also, direct fire control failures play a role in fratricide. Such failures are a result of improper planning to prevent firing into friendly positions by units conducting either offensive or defensive operations. Finally, reporting, crosstalk, and battle tracking failures contribute to fratricide by reducing awareness of friendly unit locations. All of these factors can be partially mitigated with proper training and experience. However,

3

the rapid pace, high stress and confusion of modern combat compound the effects of situational awareness failures.

The second major cause of fratricide is poor target identification. Positive target identification is the immediate, accurate, and dependable ability to visually discriminate between friend and foe [Ref. 4:p. 3]. Three main factors that lead to poor target identification are extended ranges, battlefield obscuration, and equipment similarities. Crewmembers, particularly gunners of armored fighting vehicles such as the M1A1 main battle tank and the M2A3 infantry fighting vehicle, often cannot visually distinguish between friendly and enemy systems at or near maximum weapons range. Tactics and doctrine focus on engagement at maximum range but crewmembers are not always able to achieve positive identification at these ranges. Currently gunners must rely on visual recognition of the target from either a thermal or optical sight picture. Additionally, battlefield obscuration adversely affects target identification. Obscuration can be critical when visual recognition is the primary source of target identification. Rain, dust, fog, smoke, and snow degrade identification capability by reducing the intensity and clarity of images. The final factor contributing to poor target identification is similarities between friendly and enemy equipment. The United States rarely fights wars unilaterally. During the Gulf War several coalition partners used the same types of equipment as the Iraqi Forces. The gunner of an armored fighting vehicle may have had less than three or four seconds to determine if the hazy outline approaching through a smoke screen is a coalition Syrian T-72 main battle tank or an enemy Iraqi T-72. Reducing poor target identification can decrease situational awareness failures.

The third major cause of fratricide is weapons systems failures. Incorrect charges on artillery rounds, misfiring weapons systems, and improper explosive charges, can all lead to fratricide. These types of errors are significant and preventable but were not considered in this analysis. Reducing target identification failures and poor situational awareness has no impact on weapons systems failures.

C.   FRATRICIDE PREVENTION SYSTEMS

There are no simple answers or solutions to the problem of fratricide. The focus of this research was on a system developed to prevent fratricide rather than on doctrinal or organizational solutions to the problem. While there has been extensive research done into non-cooperative fratricide prevention systems that use Automatic Target Recognition (ATR) based on size, shape, or passive signature, the focus of current Army efforts is on the development of cooperative fratricide prevention systems. Cooperative systems are based on a transfer of information between systems that assists in the identification process. This section describes various categories of cooperative, fratricide prevention systems and concludes with the discussion of the Battlefield Combat Identification System (BCIS).

1.   Target Identification Systems

The Army is developing several systems to aid in target identification. Pointing systems align with the weapon or weapon sight and are pointed at the intended target prior to firing. These systems use a signal processing system and signal beam patterns to assist with target discrimination. Friendly platforms must be equipped with transponders to read and respond to the incoming signals and provide feedback to the shooter system.

Cryptographic and transmission security measures are required on pointer systems to minimize vulnerability even though the systems use a unidirectional signal. A unidirectional signal minimizes the vulnerability because an enemy signal collector must be along the direction of the beam to collect the signal. Pointing systems are highly reliable but all friendly vehicles must possess the components.

"Don't Shoot Me" (DSM) Systems rely on Global Positioning System (GPS) positional information. The shooter determines the potential target's coordinates using onboard sensors. The shooter then broadcasts a message on either an existing data link or a specific identification data link containing the target's coordinates. Friendly systems located near the broadcast coordinates automatically respond with a "Don't Shoot Me" message. These systems are reliable but also require that all friendly vehicles possess the components. Transmitted signals are omni-directional so the cryptographic and transmission security measures are even more important than for pointing systems. Omni-directional signals are transmitted in all directions, allowing the enemy to collect the signal from anywhere on the battlefield.

2. Situational Awareness Systems

Situational Awareness (SA) Systems assist crew members by providing additional information about known friendly and enemy positions on the battlefield. Situational awareness systems use periodic updates of GPS positional information to update all friendly positions linked to the data net. The shooter uses an interface or situational awareness appliqué to correlate friendly positions with the weapons sight/sensor information. If a friendly vehicle cannot clearly discriminate the target's physical

characteristics, he may rely on his knowledge of the battlefield to assist with target

identification. These appliqués have many other uses besides fratricide prevention. They

increase a unit's overall effectiveness by providing timely and accurate locations. This

information is invaluable in planning and de-conflicting both fire and maneuver control

measures, enhancing a unit's situational awareness. The disadvantage of situational

awareness systems is correlating friendly positions viewed on an independent appliqué

with the gunner's sight picture. At some point in the engagement process the

crewmember must correlate the situational awareness information from the appliqué with

the picture in the optical sight. A situational awareness system that can pass the

situational awareness information to the crew members in a clear and concise manner is

critical to the modern battlefield. [Ref. 5]

3. Battlefield Combat Identification System (BCIS)

a. BCIS Description

BCIS is a pointing fratricide prevention system. It is a cooperative, all-

weather, digitally encrypted question and answer system that electronically queries a

potential target to determine friend or foe. BCIS uses a directional, millimeter wave

(mmW) radar signal aligned with the sighting system to interrogate unknown vehicles.

The gunner initiates interrogation by activating the weapon's laser range finder. A

friendly vehicle's transponder responds electronically and immediately to the query and

provides a flashing visual indicator in the gunner's reticle and a pulsing audio tone across

the vehicle intercom. If the interrogation is successfully sent and no response is received

from the potential target then the response is characterized by BCIS as 'unknown'. The

7

'unknown' signal is a constant color indicator displayed in the sight and a constant audio tone (the audio tone is present in the version mounted on the M2/M3A2 Bradley Fighting Vehicle but not the M1A1 main battle tank). If the gunner receives an 'unknown' response then another means is required to identify the vehicle; the potential target still may not be an enemy vehicle.

BCIS has several advantages over other fratricide prevention systems. One advantage is the system operates directly through the sight. Feedback from the gunner's electronic query is applied directly onto the sight reticle allowing the gunner to receive immediate feedback without loosing target acquisition [Ref. 5]. Another advantage to BCIS is that it uses a unidirectional signal, as opposed to an omni-directional signal. Unidirectional signals generate electronic signatures that are far less detectable than omni-directional signals, limiting user vulnerability. A third advantage to BCIS is that the gunner does not lose time during the engagement sequence by referencing a separate interface to correlate target location with the gunner's sight picture, since BCIS information is provided directly to the gunner's sight picture. Also, the BCIS is non-intrusive since neither the shooter nor the target vehicle has to conduct any additional tasks when engaging a target or responding to an interrogation. In fact, occupants of the targeted vehicle may not be aware of the electronic query. Finally, BCIS operates in the millimeter wave frequency band that penetrates most weather conditions and battlefield clutter/obscuration, and is extremely hard to detect or jam [Ref. 6].

One disadvantage to BCIS is cost. Placing BCIS on every Army vehicle is extremely expensive. There are less expensive variants of the system that allow non-firing vehicles to respond to queries but do not have interrogation components. Another disadvantage is that the system interrogator is boresighted to the vehicle's targeting system and the response antenna is located on the turret. Such a configuration creates reliability and alignment issues. Also, systems attached to the exterior of armored vehicles must withstand a great deal of punishment during cross-country maneuvering.

Select Army units are now testing a digital data-linked version of BCIS (BCIS DDL). The data-linked version provides crew members the same query capability as baseline BCIS. Additionally, BCIS DDL broadcasts target identification information to other systems operating on the same data net. On a separate omni-directional antenna, BCIS DDL uses the open BCIS frequencies in the data net to broadcast location and disposition information to properly equipped vehicles. Thus, vehicles are able to exchange knowledge about the exact location and disposition of other friendly BCIS-equipped systems. This system greatly enhances situational awareness for all team members by resolving many of the failures outlined above [Ref. 7:p. 127]. BCIS DDL uses the same set of frequency channels that it conducts interrogations on to pass the situational awareness information but broadcasts the information on unused channels in that set. The current configuration of BCIS DDL provides location and disposition information directly to the other users on the data net but does not have an interface to display it. The information shared on the data net must be displayed to the user on some other type of situational awareness appliqué or system on the vehicle. BCIS DDL

information can be used to update the information on the situational awareness appliqué even though most of these appliqués operate in a separate data net, on a separate range of frequencies. If the receiving vehicle uses an appliqué for situational awareness, then the BCIS DDL signal must be able to interface with and display information using the appliqués protocol. BCIS DDL use a unidirectional signal to conduct interrogations and an omni-directional signal to broadcast situational awareness information. The mmW signal used by BCIS DDL has a limited range when used as an omni-directional signal. Along with the weak signal, BCIS DDL has the additional disadvantage of offering a greater detectable signature to the enemy when broadcasting omni-directional situational awareness information.

b.   BCIS System Parameters

BCIS emits a unidirectional frequency at 38Ghz. This frequency band allows the signal beam width to remain within +/- 22.5 mils (1.3 degrees) of the emitted azimuth. Referred to as azimuth discrimination, the restricted beam width prevents detection of the signal at more than 3000 meters and three degrees off of the boresight azimuth. Signal spreading from the emitted/ boresighted azimuth at extended ranges can cause interrogation errors. The gunner/shooter must be aware of this potential error. Friendly and enemy systems that are located close together or located along the same azimuth from the shooter (shooting over the top of a friendly vehicle) can produce a faulty return. An important component of BCIS is it's ability to discriminate ranges and prevent this fault. BCIS uses signal times to determine the distance to the target and compares that distance with the distance returned by the weapon's laser range finder. If

the BCIS range is within 30 meters of the range returned by the laser, the system assumes

the correct target was queried. If more than 30 meters difference exists, BCIS begins the

query again [Ref. 8:p. 72-78]. It is also possible that a destroyed friendly vehicle could

still have a working transponder, allowing an enemy vehicle positioned near the

destroyed vehicle to be identified as a friendly vehicle.

The major system performance parameters are listed in Table 1 [Ref. 8:p.

72-78].

Parameter	Description	Value	Modeled As
Operational Range	Range of mmW signal under various conditions	5.5 km (Clear/Fog) 5.0 km (Oil) 3.0 km (Dust/Rain)	5.5 Km only
Probability of ID	Probability identifying friend under worst case	~.925 to .97	~ Unif.(.925,.97)
Identification Time	Time from interrogation to visual indication	~ 1.0 sec	~ Unif. (.92,1.0)
Discrimination	Azimuth discrimination	+/- 22.5 mils (1.3 Degrees)	Not modeled
Probability of Interrogation	Probability of interrogation successfully sent and received by transponder	Unknown	.996 [Ref. 9]
Probability of Reply	Probability of reply successfully sent and received by interrogator	Unknown	.996 [Ref. 9]
System Reliability	System is working	Unknown	.975 (estimated)

Table 1. BCIS System Parameters

BCIS achieves a high degree of reliability by conducting three different

identification cycles within the one second identification time (each about .3 seconds).

11

Each .3 second cycle has a random delay time of between 0.01 to 0.05 seconds between cycles. Independent test data indicates that the probability of correct identification is about 92.5%. This is lower than the manufacturers claims of 97% but all of the failures in the independent test were from the interrogator receiving signals from multiple transponders [Ref. 10:p. 97].

D.   THESIS ORGANIZATION

The remainder of the thesis will be organized as follows. Chapter 2, Problem Statement, describes the specific problem. Chapter 3, Simkit Functions, outlines the capabilities of Simkit, the simulation used to model BCIS. Chapter 4, BCIS Engagement Model, explains the conduct of fire process that is modeled in the simulation. The chapter discusses how each part of the conduct of fire process is modeled in the simulation and the algorithms and methods implemented in the simulation. The scenarios used in the simulation and the measures of performance used for analysis are defined in this chapter. Chapter 5, Results, describes the statistical tests used for the data analysis, provides test results and analysis of the results. Chapter 6, Conclusions, draws conclusions about the experimental results and suggests recommendations for future research.

II. PROBLEM STATEMENT

The J-8 Simulations and Analysis Management Division is assessing the impact of both combat identification (CID) systems and situational awareness systems on tactical doctrine. Specifically, the Joint Staff wants to know how CID and SA systems affect doctrine and force structure. To answer this question CID systems must be accurately modeled. The purpose of this thesis was to answer the following question: Does the Battlefield Combat Identification System improve combat effectiveness, defined as increased lethality and reduction in fratricide. This question was answered by analyzing different versions of BCIS and determining how each system improved combat effectiveness.

To analyze the effects of BCIS, the system was modeled with the Simkit (JAVA) simulation package [Ref. 12]. Scenarios involving BCIS-equipped M1A1 main battle tanks conducting a hasty defense and movement to contact against an enemy force were executed in Simkit. Measures of performance were then examined across both missions for three different cases:

- Tank Company not equipped with BCIS (No target identification or situational awareness capability);

- Tank Company equipped with BCIS for target identification only (target identification capability but no situational awareness);

- Tank Company equipped with Digital Data-Linked BCIS (both target identification and situational awareness).

This thesis conducted an analysis of the different levels of BCIS to determine if BCIS improved the combat effectiveness of a tank company. The BCIS model developed in Simkit also provides a tool for future analysis of the BCIS system.

III. SIMKIT FUNCTIONS

BCIS was modeled using Simkit, a Java based, simulation package developed at
the Naval Postgraduate School (NPS) by Professor Arnold Buss and LT Kirk Stork, U.S.
Navy [Ref. 12]. Studies in target identification systems have been done using various
other simulations but it is often unclear how a new system is being modeled or how the
performance characteristics of a system have been modified to fit within an existing
model. Previous BCIS studies were conducted using CASTFOREM at the U.S. Army
TRADOC Analysis Center, White Sands Missile Range [Ref. 9]. Other simulations were
considered such as JANUS and CASTFOREM to model BCIS but Simkit simulation
package was selected due to the author's familiarity with Simkit and the robust Java
component libraries currently available at NPS. Simkit had the flexibility to model
specific BCIS functions that was not available in other simulations.

A.   EVENT STEP DESIGN

Simkit is a discrete event simulation package that avoids some of the drawbacks
of time step simulations. Many military simulations are currently executed by the
movement of time in fixed intervals. After the time clock advances a particular time
interval, the state of all the objects in the simulation is updated. Movements, casualty
adjudication and supply consumption are all calculated. Time step simulations, while
easier to program and develop than event step simulations, are costly in terms of
computing power and needless computations. Every object in the simulation is examined

15

relative to every other object in the simulation to determine if any interactions between these objects have occurred. Most of the time the answer to the interaction question is 'no' resulting in increased processing overhead. Secondly, in a time step simulation the size of the time step can effect the outcome of the simulation. There is no precedence established for events that occur within the same time step. In the scenarios being developed for this thesis, the difference between which vehicle fires first may be a matter of seconds. A time step of one second would be appropriate for this model, resulting in interactions and computations being updated every second. Even with a small number of objects, the model would perform an extraordinary amount of calculations and the model would not be able to adjudicate between near simultaneous combat actions. Objects that had been destroyed would still be allowed to return fire within the same time step.

The solution to these issues is the event step model. In an event step simulation, a master event list schedules all pending actions. Events are scheduled onto the master event list in the order of their time stamp only when events of interest occur. For instance, a tank's movement along a specific route is not of interest until it reaches it's destination or it detects something along the route. A time step model would ask the tank every second how far has it traveled or what its current position is. The event list is a dynamic list of expected actions. Processing events on the event list can also trigger the addition or removal of other events [Ref. 11:p. 21].

B. SIMKIT COMPONENTS

The simulation model is divided into two classes of simulation objects to represent physical systems, mover and sensors, and a third class of objects that oversees

16

the interactions between the mover and sensor classes, the mediator and referee class. Additional classes support and provide information for the actions of the primary objects.

1. Sensors

The sensor class in the model is the *M1BasicSensor*. Once instantiated, the *M1BasicSensor* controls all target acquisition, target identification and target engagement. Most of the actions that control the specific target engagement algorithms are located in the Sensor class. *M1BasicSensor* also accesses other classes to make use of required algorithms to perform acquisition and identification functions.

The best way to think of the actions of the sensor is to place a series of concentric rings around the sensor. The sensor uses a cookie cutter model to determine objects of interest based on the relative geometry of the two objects. If an objects relative motion causes it to enter the sensor's active radius, a simple calculation determines when entry occurs and places the 'EnterRange' event on the master event list. There was some concern with modeling the main sensor of an armored vehicle as a circle. Despite the fact that the sensor of a armored vehicle has a limited field of view, the sensor as modeled in Simkit covers 360 degrees. The remainder of the crew can observe in other directions, providing sufficient warning to bring the main sensor of the fire control system to bear upon a potential target. The *M1BasicSensor* class can easily be extended to model a limited field of view for the tank. Figure 1 shows the *M1BasicSensor* object and it's rings of concern in the BCIS model. In this figure, the detection range is the outside circle. Based on when the potential target is actually detected, the target may be within the sensor's weapons range.

17
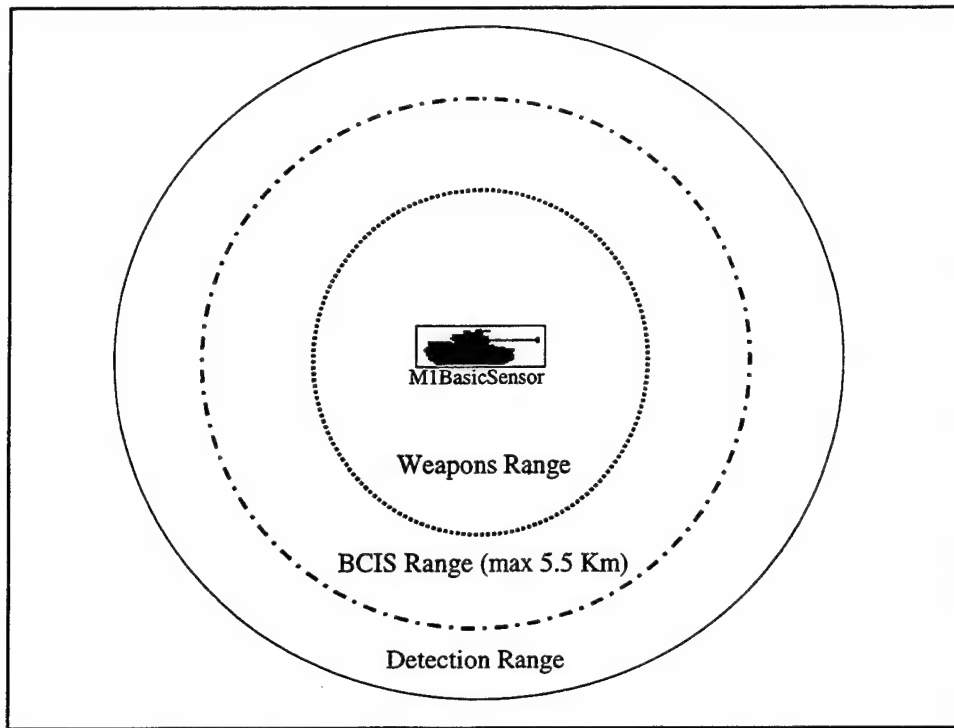
Figure 1. Sensor Rings

The sensor receives information about other simulation objects from a mediator whenever another simulation object is going to enter into the sensor's cookie-cutter ring of detection. The sensor then continues to track the object as a potential target, determining when it is within range of it's BCIS (if available) and within range of its weapons systems. Times for each of these events are calculated based on the relative location, direction and rate of movement of the simulation objects and placed on the master event list. Target destruction, sensor destruction, or changes in motion can alter the scheduled events and cause other events to be added and removed from the master event list as required. A target entering the sensor's weapons range initiates the sensor's target classification and engagement processes. Once the engagement process begins, the

18

only thing that can stop that process is the death of either the sensor or target, or if the target moves out of range. Sensors can track several different targets at the same time. The sensor maintains a list of all detected and potential targets within its view and continuously updates which targets are classified as most dangerous.

For the armored vehicles in this simulation, the *M1BasicSensor* class acts as the fire control system for the main weapon on the vehicle. As the fire control system, the *M1BasicSensor* class, also models the primary weapon. This class determines when to fire the main gun, and when the main gun hits and destroys the target. There is no need in this simulation to use a separate class to model the weapons system.

2. Movers

Movers are the generic objects of motion in the simulation, and the concrete mover class in the model is the *M1BasicMover*. A sensor is incapable of motion and must be placed upon a mover to travel across the battlefield. The Mover-Sensor combination is the lethal pair that becomes the armored fighting vehicle. The mover cannot move entirely on his own. The *M1BasicMover* must have a controller to direct its actions much like a tank driver provides the necessary inputs. In this model the *SystemMoverManager* class provides direction to the mover. The *SystemMoverManager* class tells the mover direction, speed, and travel time.

Two other important concepts are needed to simulate motion. First, the simulation object travels within a two dimensional Cartesian coordinate system. Although the model does not use elevation data, the model and the Simkit simulation package could easily support elevation parameters. Using a two dimensional coordinate

19

system allows the simulation to model the motion of the movers with basic linear motion. Although most armored vehicles in combat change direction and speed routinely for survivability, movers move with constant velocity from directly from point to point. Compared to the speed of a tank round, these nonlinear motions are insignificant and were not modeled. The classes used for the coordinate reference system and for the linear motion were all part of the Simkit class libraries [Ref. 12].

3.   Interactions

The main interactions between movers and sensors are supervised by two classes: referees and mediators. The referee serves as the master bookkeeper over interactions between sensors and targets. All movers and sensors register with the referee. The referee 'listens' to each of the actions of the movers and reacts when appropriate. If the geometry of two objects indicates that there may be an interaction between these objects, the *Referee* class creates a mediator to manage the interaction between these two objects. In this model the *CombatIDMediator* class manages all interactions between the mover and the sensor. The *CombatIDMediator* class uses algorithms to determine when a detection occurs and schedules that detection on the master event list. The *CombatIDMediator* class also notifies the sensor when the sensor will see the target and passes visual information about the target. *CombatIDMediator* keeps track of any changes in the interactions between the objects, specifically if the engagement between the two objects results in one of the objects being destroyed. The *Referee* class is part of the Simkit library [Ref. 12], and the *CombatIDMediator* class is a modification of the work done by both Professor Arnold Buss and LT Arent Arntzen [Ref. 13:p. 22].

4. Supporting Classes

There are two major supporting classes that were built specifically for this model. They are the *Atmosphere* class and the *SystemType* class. The *Atmosphere* class serves as a reference for the weather, terrain, and obscuration conditions needed to determine target acquisition and detection. When supplied with a given geographic area (either Southwest Asia or Europe), time of day, season, and maximum visual range, the *Atmosphere* class provides the detection algorithm atmospheric values needed to compute target contrasts and atmospheric attenuation. This class also controls the effects of obscurants on target detection.

The second major supporting class is the *SystemType* class. Each Mover-Sensor combination represents a specific type of military vehicle. The type of military vehicle is designated by an enumerated value. The *SystemType* class provides the Mover-Sensor combination a set of specific characteristics based on the enumerated value. The *SystemType* class also provides a system type tag to each combination to allow easy reference to system types. The *SystemType* class currently supports three types of friendly systems, and four types of enemy systems. More system types can be added with type numbers 1 - 20 reserved for friendly systems and 21 - 40 reserved for enemy systems. If the analyst fails to provide a specific system type, the model defaults the Mover-Sensor combination to a generic tank type vehicle.

Additional supporting classes in the Simkit basic libraries were used in the simulation model. Classes that supported random number distribution and random

number seeds (*RandomStream*), statistical calculations (*SimpleStats*), and a two

dimensional coordinate system (*Coordinate*) were used extensively.

IV. BCIS ENGAGEMENT MODEL

This chapter describes the conduct of fire process, discusses methodology used for acquiring, classifying, and engaging targets, and describes how these concepts are applied to the BCIS model. The chapter's focus is how the conduct of fire is applied to armored vehicles (tanks or infantry fighting vehicles). The chapter also addresses how the conduct of fire process is further implemented into a simulation model. It also describes the specific algorithms and methods that were used in the model to accurately represent the conduct of fire process.

A.   CONDUCT OF FIRE PROCESS

The conduct of fire process is a series of progressive and interdependent steps taken by a tank crew to acquire, classify, and engage enemy targets. The six steps in the conduct of fire process defined by the U.S. Army Armor Center [Ref. 10] are:

- Crew Search
- Detection
- Location
- Identification
- Classification
- Confirmation

Crew Search is the cooperative effort of crew members to determine whether objects of military interest are within view of the vehicle. The crew performs the search function using the unaided eye, handheld optical devices (binoculars or night vision devices), or powerful vehicle optical systems. Each crew member establishes a primary sector of responsibility to focus his visual search. The vehicle's gunner uses the vehicle

optical systems to search the most likely enemy sector. When operating as a unit, designated vehicles may be responsible for specific sectors, ensuring 360-degree coverage.

Detection is the observation of an object, often just a signature or silhouette, that has the potential to be a military target. Dust trails from vehicle movement, noise, movement of vegetation, thermal or infrared hot spots, and flashes from gunfire can provide signatures. Observing and properly interpreting signatures allows the crew members to focus more powerful sensors onto a system to determine whether it is a military target.

Location is the next step in the conduct of fire process. By referencing a map, using a laser range finder or estimating from a know reference point, crews members can pass location information about a potential target to other crew members or vehicles in the unit.

Identification is the ability to determine if a potential target is a friendly or enemy system. The crew member must assess physical traits of the potential target (size and shape) to determine if the system is a threat. Currently the only method available to an armored crew member to identify a target is visual identification. As the distance from the target increases, and visibility based on battlefield conditions decreases, identification becomes increasingly more difficult. The challenge increases during periods of limited visibility due to darkness, obscurants, or inclement weather.

Classification is the grouping of targets by the threat level that they represent to the vehicle and crew. The general classifications are most dangerous, dangerous, and

least dangerous targets. Generally, a most dangerous target is a target that has the capability to destroy the friendly vehicle. The crew categorizes targets to determine which pose the greatest threat to the crew. A dangerous target has the capability to destroy you but is either not actively looking for targets or is performing another function. A least dangerous target may not be able to destroy your vehicle but may have a higher engagement priority for the assigned mission (such as an air defense weapon system). The BCIS simulation model developed in Simkit uses the closest target as the most dangerous target. This technique to determine classification is suggested in gunnery manuals when the crew is in doubt.

The most important step in the conduct of fire process is target confirmation. To confirm the target, both the gunner and the vehicle commander verify target identification and target classification prior to firing. Confirmation occurs as the final step of the conduct of fire process, as the gunner is firing [Ref. 10; Ref. 14] .

The entire conduct of fire process takes place over a short period of time -the standard in the tank gunnery manual, FM 17-12, is 12 seconds. It is possible to track targets for several minutes before they come within range of the weapons system. Generally, US forces seek to engage the enemy at maximum range to ensure maximum force protection.

The actions of the vehicle's crew in the BCIS simulation model closely follow the six-step conduct of fire process. The crew conducts a series of tasks controlled by the fire commands issued by the vehicle commander that guide the crew through the conduct of

fire process. This crew engagement drill is important in understanding the capabilities and effects of BCIS and is modeled in detail in the BCIS simulation model.

The simulation models the search, detection and location steps of the conduct of fire process in the manner described above. There are other important aspects of the crew engagement drill modeled in the system. Upon detection of a potential target, the crew is alerted, allowing the vehicle gunner to place more powerful optics onto the potential target to assist in identification. The remainder of the crew ensures that the main gun is loaded, the vehicle is presenting as small a signature as possible, and the search process continues. The gunner and the vehicle commander both use system optics to determine vehicle identification. The gunner may change between different levels of magnification and different optical and thermal sensors to achieve identification. Changing between different levels of magnification is part of the process that is modeled in the simulation. Detecting a target is often easier in lower levels of magnification, whereas identification is easier at higher levels of magnification. Once an enemy vehicle system is detected the gunner activates the laser range finder to determine range to the target. On the M1A1 MBT, the fire control system's ballistic computer uses the input from the laser range finder and 11 other inputs (tracking speed for moving targets, cross wind reading, temperature readings, vehicle speed, cant, barometric pressure, ammunition types, tube wear, and computer correction factors) to compute a solution to the target [Ref. 10:p. 2-3]. In the BCIS simulation model, the firing solution is based solely on the range to the target and these other inputs to the tank's fire control system are not modeled.

The gunner employs BCIS at this point in the crew engagement drill. When the gunner interrogates the target, BCIS provides an indicator whether the target is friendly or unknown, potentially saving the gunner seconds or even minutes during the identification process. If the gunner receives an 'unknown' response from BCIS or if BCIS is not operational, then he must continue to confirm visual identification using some other method. This part of the crew engagement drill is also represented in the same manner in the BCIS simulation model.

B.   MODEL METHODOLOGIES

The model uses different methodologies and algorithms to model the conduct of fire process and crew engagement drills in the simulation. The methods ask a series of questions to determine more information about the target and help the crew decide to shoot. Figure 2 outlines the conduct of fire process and identifies which algorithms or methods are used in the BCIS simulation model for each part of the process. The focus of this section is to describe how the conduct of fire process was modeled in the simulation. APPENDIX B provides detailed flow charts of the process and the related algorithms.
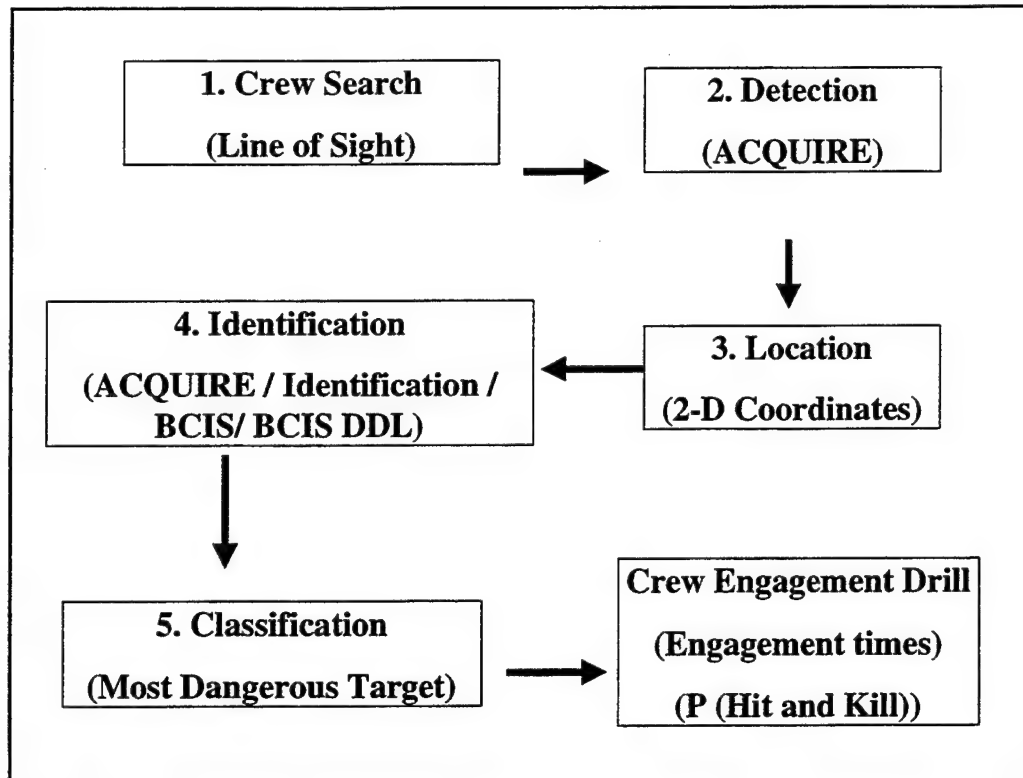
Figure 2. Modeling the Conduct of Fire Process

1.   Line Of Sight Algorithm

Determining of line of sight (LOS) is an important consideration for any combat

modeling process. Terrain is often the limiting factor for line of sight. It is possible in

some terrain conditions, particularly in the desert, to have line of sight beyond the

maximum range of the system. However, vegetation and elevation changes normally

preclude this from happening.

Line of sight can be modeled either explicitly or implicitly. Explicit models use a

terrain representation in which they attempt to store terrain features by representing

terrain in either a grid or data point that stores information about the represented terrain.

Explicit model calculations involve determining if there is anything between the target

and the observer that would preclude line of sight. Elevation or man made structures could impede line of sight. The data required and detail involved to compute LOS varies with the level of resolution and the detail of the database. These LOS computations and representations can be very expensive in terms of computing power [Ref. 15:p. 49].

The BCIS simulation model, as implemented in Simkit, uses an implicit terrain representation. Implicit terrain representation, does not involve a specific terrain representation but rather preprocesses and pre-computes line of sight calculations across a given terrain battlefield. Then, look up tables or probability distributions are used to determine line of sight. An approximate representation was made of a terrain board that implied open, central corridor of high desert terrain bounded by mountainous terrain of reduced vision. It was important that BCIS was not always being used at maximum range but rather at a variety of different ranges. Figure 3 depicts how line of sight was modeled in the BCIS simulation based on the position of the observer. If the mediator determined that a potential target was within sensor range of the observer, the mediator queries the observer position. Based on which zone (A, B, or C) the observer was in, a random uniform distance (See Figure 3 for the distances for each zone) was drawn to determine how far the observer could see from his current location. If the potential target was within that distance, the normal detection process began. If not, the mediator determined at what time the potential target would be in the observer's line of sight and scheduled that event on the master event list. For example, an observer in zone B can see between 2 and 4 Kms.
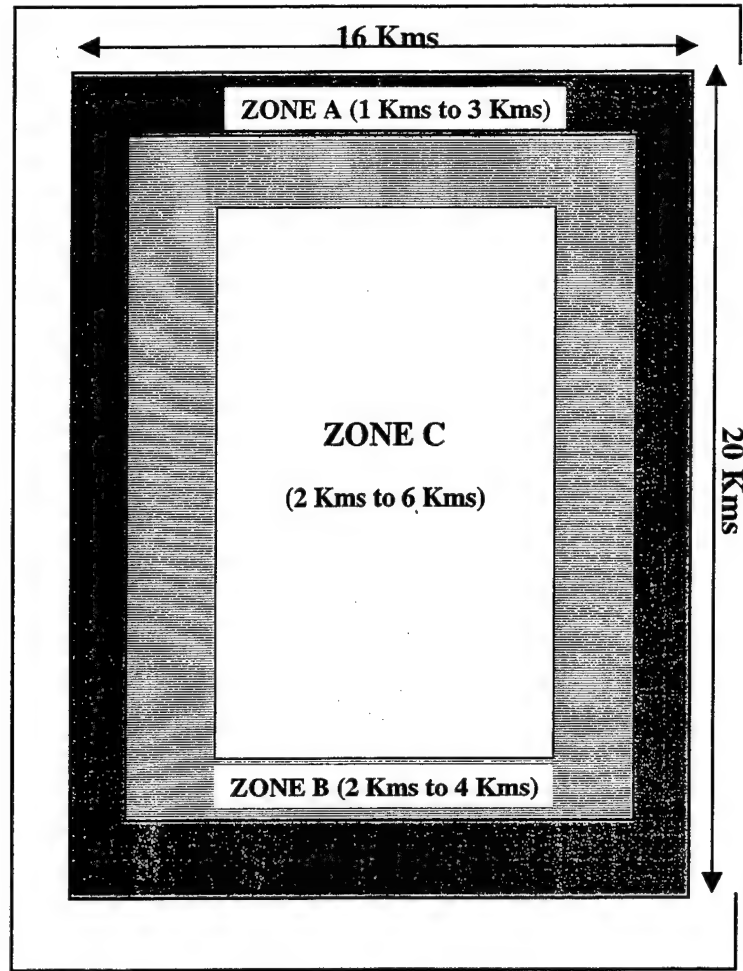
Zone A - Line of Sight between 1 and 3 Kms
Zone B - Line of Sight between 2 Kms and 4 Kms
Zone C - Line of Sight between 2 Kms and 6 Kms
Figure 3. Line Of Sight

2. ACQUIRE Algorithm

The ACQUIRE algorithm was adopted in 1993 by the Army as the

standard for target acquisitions models for ground combat simulations [Ref. 16]. The

ACQUIRE algorithm was modeled in detail in the BCIS simulation model and

determines when a target is detected. The ACQUIRE algorithm also determines how long

30

it takes to identify the potential target if the vehicle is not equipped with BCIS or if the BCIS returns an 'unknown' response. The ACQUIRE algorithm uses the Johnson Criteria to represent various levels of target acquisition. The Johnson Criteria was developed through extensive experimentation to equate the number of cycles in milliradians or line pairs at which half of all observers can identify a target on a standard target board. It is a modified version of a similar methodology developed by the U.S. Army Night Vision Laboratory. The levels of target acquisition that are represented in the ACQUIRE algorithm are shown in Table 2 [Ref. 17:p. 2-2]. This thesis will refer to the ACQUIRE levels of target acquisition by number to avoid confusion with other terms. The value for the criterion is a model parameter but less important than noting that the criterion doubles for each successive level of acquisition that is required.

ACQUIRE Acquisition Level	**Criteria (cycles/milliradian)**
Level 1 - distinguish an object of military interest	0.75
Level 2 - distinguish by target class, e.g. wheeled or tracked vehicle	1.5
Level 3 - distinguish between different types in a class, e.g. truck vs. jeep	3.0
Level 4 - distinguish between different models, e.g. T80 vs. M1A1	6.0

Table 2. ACQUIRE Target Acquisition Levels and Line Pair Criteria

The ACQUIRE algorithm uses four categories of input parameters to determine the level of acquisition: sensor data, atmospheric data, target data, and scenario data. The ACQUIRE algorithm is used for direct view optics (DVO), image intensifiers (I2), and thermal infrared (IR) sensor systems. Almost all visual ground combat optics falls into these three categories. Each sensor in these three categories has a specific data set that defines it's performance called a minimum resolvable contrast (MRC) or

minimum resolvable temperature (MRT) data set. For the BCIS simulation model, all of

the vehicles, including Russian systems, used performance data derived from the M1A1

MBT / M2 IFV sensor systems. No unclassified documentation was found that compares

the M1A1 sensors with the systems currently used on modern Russian combat vehicles,

but similar performance is expected. Other sensor input into the ACQUIRE algorithm

includes the field of view of the sighting system in each of the different levels of

magnification and the power of the optics at that magnification level. Field of view and

magnification characteristics from each vehicle type were used in the BCIS simulation

model.

The ACQUIRE algorithm in the BCIS simulation model uses atmospheric

data from two large data sets: Central European and the National Training Center. These

terrain data sets provide average values for atmospheric contrasts, transmission of visual

light and ambient attenuation based on times of day, light levels, times of the year and

average range of visual observation. The BCIS simulation model receives user input as

to which of the two terrain databases most closely resembles the ground where the battle

is being fought. The user also inputs average visual ranges and seasons. The BCIS

simulation model determines the time of day from the simulation clock. The time of day

also determines which sensor to use to acquire targets. Thermal sensors are used from

2000 hours to 0800 hours in simulation time. The BCIS simulation model uses DVO

sensors during all other time periods.

In addition to accounting for atmospheric conditions, the ACQUIRE algorithm

can be used to approximate the obscuration provided by battlefield effects such as smoke,

fog oil, and dust clouds. The ACQUIRE algorithm assumes uniform obscuration for various types of clouds and does not attempt to capture the effects of wind or delivery effects. Obscurant coefficients can be incorporated into the BCIS simulation model but were not used in this study.

Target dimension data for the ACQUIRE algorithm included both the target's front and side cross sectional areas and the target's action. One of the drawbacks of the ACQUIRE algorithm is that it does not model pinpoint acquisition [Ref. 16:p. 2-3]. A moving target or a target that is firing provides the searcher with a visual cue to bring the observers eyes and search pattern directly to the target. This cue 'pinpoints' the target location and where the crew should search for the target. Modifications (multiplication factors) were made to the ACQUIRE algorithm for uses in this thesis to correct these deficiencies. Table 3 shows the modifications used.

Target Action	Modification to Line Pair Criteria
Stationary	None - values from Table 2
Moving, not firing	x2
Firing, not moving	x3
Moving and Firing	x4

Table 3. Pinpoint ACQUIRE Algorithm Modifications

For example, this table says that an observer is twice as likely to see a moving target the is not firing than a stationary target. Army Material Systems Analysis Agency (AMSAA) tests have shown that a line pair criteria of 0.5 can be used with a moving target and pinpoint acquisition of a firing target can approach 100% as the muzzle flash gets closer to the observer's field of view [Ref. 17:p. 2-3]. These tests support the multiplication modifications used in the BCIS simulation model from Table 3.

33

Other input parameters to the ACQUIRE algorithm include desired acquisition level, range between the target and the observer, size of the area across which the sensor is scanning and search times. For the BCIS model the desired level of acquisition used was level 3, the ability to distinguish between different categories of targets within a class. This level of acquisition is critical to determining the level of threat that the target represents to the observer. The size of the sector being observed or field of regard was also an input to the model. The ACQUIRE algorithm used a sector of 120 degrees.

The ACQUIRE algorithm determines the probability of detection for a target as a function of sensor characteristics, target characteristics, terrain and atmospheric conditions, desired level of acquisition, and range to the target. The probability of detection is calculated based on the amount of time the observer is looking for the target. Because the BCIS model is not based on fixed time steps but on discrete event steps, the model uses random draw to determine the probability of detection. Substituting this probability into the algorithm's detection distribution function, the simulation model computes the time at which the detection is made. The detection time is scheduled on the master simulation event list. The simulation also uses the ACQUIRE algorithm to determine the time required to reach acquisition level 3 if the vehicle is not equipped with BCIS or BCIS gives an unknown return and identification must be accomplished by some other method.

Verification, validation, and accreditation tests conducted on the ACQUIRE methodology indicates that it can accurately predict target acquisition to within 20% of a given probability [Ref. 17:p. 2-2]. The BCIS simulation model implementation of the

ACQUIRE algorithm does not differ from the original ACQUIRE algorithm, and can be expected to perform equally well.

3. Identification Process

a. *Without BCIS*

The ACQUIRE algorithm does not assume a positive target identification unless the observer is operating under acquisition level 4. It is possible to operate under a lower level of acquisition if the rules of engagement dictate, but the algorithm still does not indicate if the vehicle was identified as a friend or foe. The BCIS model uses a simple probability analysis to determine target identification. The BCIS simulation model determines the base probability that a vehicle is either friendly or enemy based on the number of vehicles of each type that are in the simulation scenario. For instance, if 33% of the vehicles in a given simulation scenario are friendly, firing at every detection gives the observer a 33% chance of hitting a friendly target. The BCIS simulation model assumes a linear increase in the probability of correctly identifying a target as the ACQUIRE algorithm level of acquisition is increased and more knowledge is gained about the target. Table 4 shows the probability of correctly determining if a target is friendly for all four target acquisition levels of the ACQUIRE algorithm, if 33% of the objects in the simulation scenario are friendly vehicles. All friendly forces without BCIS and all enemy forces used acquisition level 3 in the simulation.

Target Acquisition Level in ACQUIRE	P(correct ID as friendly)
Level 1	0.3333
Level 2	0.5367
Level 3	0.7433
Level 4	0.9500

Table 4. Target Identification Determination

35

The BCIS simulation model provides additional information to enemy vehicles (through use of a vehicle list that they cannot engage) to ensure that the enemy does not commit fratricide. This was done for the analysis to ensure that enemy forces were engaging friendly vehicles rather than firing on each other. Test scenarios indicated that the results of the analysis could be affected by a large number of enemy fratricide incidents and few enemy vehicles surviving to fight the friendly force.

b.   With BCIS (no Situational Awareness)

BCIS is modeled using a much higher probability of identification than the ACQUIRE algorithm. Using the system parameters outlined in Chapter 1, the probability of a correct BCIS return or correct identification is between 92.5% and 97%. The model conducts random uniform sampling between these values to determine the probability of BCIS being correct. There is also a chance that the BCIS signal will not be correctly processed by the target transponder or that the observer's interrogator will not correctly receive a response to the transmitted signal. Finally, there is the chance that the system is non-operational. Based on limited field use of the system, BCIS reliability is unclear. As with any piece of equipment on a combat vehicle it may sustain damage from battle, the environment, or normal wear. A reliability rate of 97.5% was assumed for BCIS, above the 95% expected readiness rate for most pieces of minor equipment. Assuming that these events are independent, the probability of BCIS returning a correct response to the gunner is [Ref. 9]

$$P1 = P(Interrogation\ successfully\ sent\ and\ received\ by\ transponder\ |\ BCIS\ is\ mission\ capable\ ) = 0.996$$

P2 = P(Reply successfully sent and received by interrogator | Interrogation successfully sent and received by transponder & BCIS is mission capable) =0 .996
P3 = P(Correct BCIS response | successful interrogation & successful reply & BCIS is mission capable) = U (0.925,0 .97)
P4 = P(BCIS is fully mission capable) = 0.975

P=P(Correct BCIS response) = P1*P2*P3*P4 = U(0.8947,0.9383) or E(P) =0 .9165

While this is less than the probability of a successful identification under the ACQUIRE algorithm using the most stringent acquisition level, it is important to note that the BCIS allows positive identification of friendly vehicles at much longer ranges than the ACQUIRE algorithm. If the target is close enough for visual identification, BCIS is confirming the identification of the gunner and vehicle commander.

BCIS reduces time to fire. Identifying a potential target as a friendly vehicle allows the crew to focus their time and efforts on identifying other targets. If the gunner receives an indicator from BCIS that the target is unknown, he must attempt to conduct a visual identification using normal visual means. The BCIS simulation model attempts to determine identification as if there were no BCIS if the initial response is unknown. An unknown return is designed to model the crew thought process to determine if the potential target is a friendly vehicle with a non-operational BCIS or a system destroyed in battle. A coalition partner may not be equipped with BCIS, requiring a similar thought process.

c. BCIS DDL (with Situational Awareness)

BCIS DDL creates an additional modeling challenge: How to model human behavior and decision making? The BCIS simulation model uses the same system parameters as the baseline BCIS to determine if the potential target in the sight is

a friendly vehicle. It is difficult to determine how often a crew will consult their situational awareness appliqué to correlate information from the appliqué to the information in the sights. The techniques and procedures to assimilate all of this information in combat are still being developed. The BCIS simulation model represents referencing the situational awareness appliqué through a time-delayed passing of information. It assumes the vehicle commander must periodically check the appliqué for updates and changes to the situation in addition to other duties. There are periods of time where the commander must be looking through the sight to confirm the gunner's target identification prior to giving the command to fire. The commander checks the appliqué after the completion of each engagement. In the BCIS model, the situational awareness information is passed to the other vehicles in the unit via the digital data link after the observing vehicle has correctly queried the potential target as either an 'unknown' or friendly vehicle. The information is available to the other vehicles in the unit after a delay that corresponds to a single engagement cycle - target detection to target destruction (15 seconds).

This BCIS DDL model incorporates an additional delay based on the amount of time that is required for the system to access the data link and send a message. This time is determined by how often the entire system DDL net and BCIS are being used. When a BCIS vehicle conducts a query of potential targets it is using a series of frequencies within the assigned frequency range to transmit and receive interrogation information. It is possible that the broadcast of the situational awareness information could be canceled out by an ongoing interrogation (interrogation messages always

receive priority). The actual system will try to rebroadcast on the next available open frequency set. As currently designed, the message is 2400 bits, and there are 64 available hop frequencies in which to send the signal. Based on how the signal is sent in relation to the frequency hopping pattern and a BCIS interrogation rate of 2 interrogations per second, this message can take from 1.096 to 1.333 seconds to transmit with a probability of .896 that it obtains an open frequency [Ref. 7:p. 146]. Using uniform random number draws the BCIS simulation model determines the number of tries required to send the message and computes the total transmission times.

An observer can now determine from his appliqué that he does not need to interrogate a friendly vehicle if someone on his data link has already done so. He can immediately move to the next target. If a BCIS interrogation returns an 'unknown' identification symbol then the model has other vehicles on the data link conduct their own BCIS interrogation prior to seeking identification by other means. Figure 4 outlines the logic used in the model for the situational awareness system.
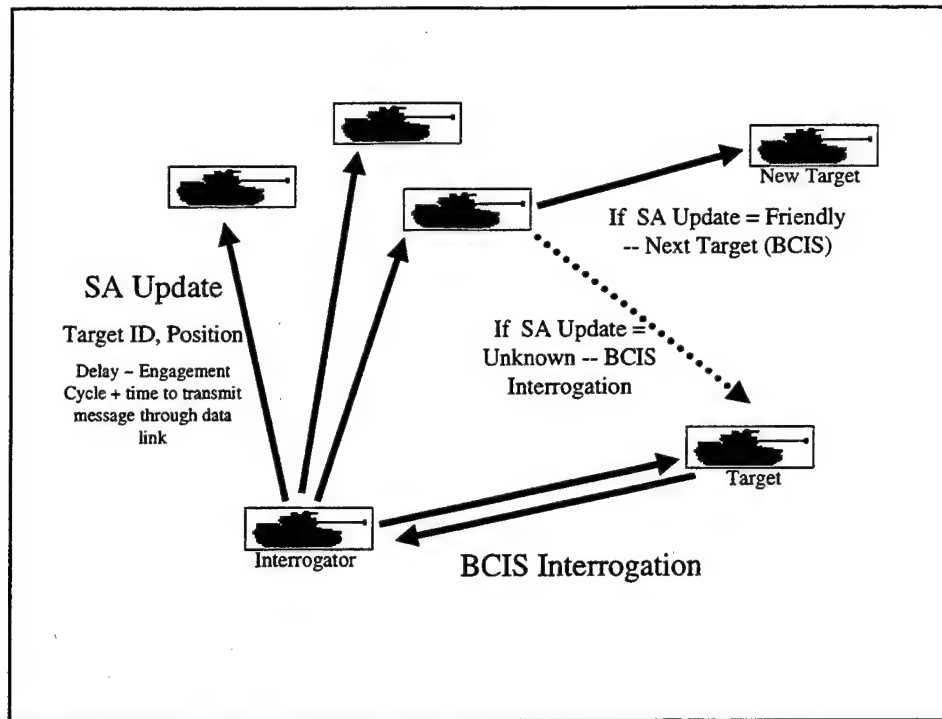
Figure 4. BCIS DDL Situational Awareness Model

4. Engagement Sequence

The crew engagement sequence used in the model is a simple representation of the real crew engagement drill. First the crew determines the most dangerous target by determining which target is the closest to the friendly vehicle. Upon selecting the most dangerous target the crew engagement drill begins and the target is fired upon. As soon as the vehicle fires at the target vehicle, he continues to reengage the target until either the shooter or the target is destroyed. The times used for the crew engagement drill were received from the Training and Doctrine Development Division, US Army Armor Center. They are from 12 different M1A1 units that conducted basic crew qualification in winter 1990. The engagement cycle time is the time required to perform the required crew drills

40

to fire at the target after the target has been detected and is within weapons range. The previous algorithms (ACQUIRE) are used to determine how long it takes to detect the target. The time to fire was determined from the defensive engagement times from the Armor Center data. During a defensive engagement the tank conducts target acquisition while in a covered position, an untimed portion of the engagement. Upon target detection, the tank moves forward from behind the cover, placing the main gun in a position to fire. Time is measured from when the main gun is exposed until the first round is fired. This time is used in the model to represent first round engagement time. The data failed to show the difference between rounds that hit and rounds that missed the target making it difficult to analyze. However, the data does provide some justification for the engagement times used in the BCIS model. There were 5 engagements from 550 different crews, ranging in time from 1 to 12 seconds. The 2750 data points had a sample mean of 4.38 seconds and a sample standard deviation of 2.29 seconds. This information was used in the BCIS simulation model for first round firing times.

Determining engagement times for the second round fired at the same target were not as easy to determine. The tank must return to a covered position, re-load, return to the exposed position, and reengage. Again, the data did not show clearly which target had been engaged first and if the difference between rounds that hit and rounds that missed. Only two of the five engagements had more than one target. The 1100 data points had a sample mean of 14.04 seconds and a sample standard deviation of 4.068 seconds. This is the value used for reengagement times in the BCIS model.

41

5.   Hit and Kill Probability Function

Hit and kill probabilities were developed for each of the weapons systems as a function of range. The data provided by the Armor Center gave insight into acceptable values for probabilities of hit, but gunnery with fixed targets on fixed ranges does not help determine the functional relationship between probability of hit and range. For the given data, all tank crews fired at both stationary and moving targets from both moving and stationary tanks. The average probability of hit was .8305 for defensive (stationary shooter) engagements, and .809 for offensive engagements (moving shooter). Most of the targets on this range were between 1400-1600 meters from the shooter. The challenge was to fit a range function to the data that allowed the BCIS simulation model to determine hit probabilities at ranges outside the data. The fire control systems for each of these weapons systems provides a consistent probability of hit until the system begins to approach the extreme end of it's maximum effective range. A negative exponential function was chosen as close approximation to the data. For the tank on tank battles used in the simulation a hit on an enemy vehicle is also considered to be a kill. Maximum probabilities of hit and kill were used for each of the weapons systems to ensure that training, system limitations, and the stress of being in combat was modeled. The formula used to determine the probability of hit and kill as a function of range was:

*P(Hit & Kill) = (1- exp (-1.25 * (Max Range – Current Range)/1000)) * P(Hit & Kill)*

Values from this range curve were also compared to probability of hit values found in the JANUS combat model's Combat Systems Database to ensure an approximate match with

42

accepted hit probabilities. Similar range curves were used for each of the enemy weapons systems. Figure 5 shows this function graphically.

US Weapons Range Functions (vs. T80)
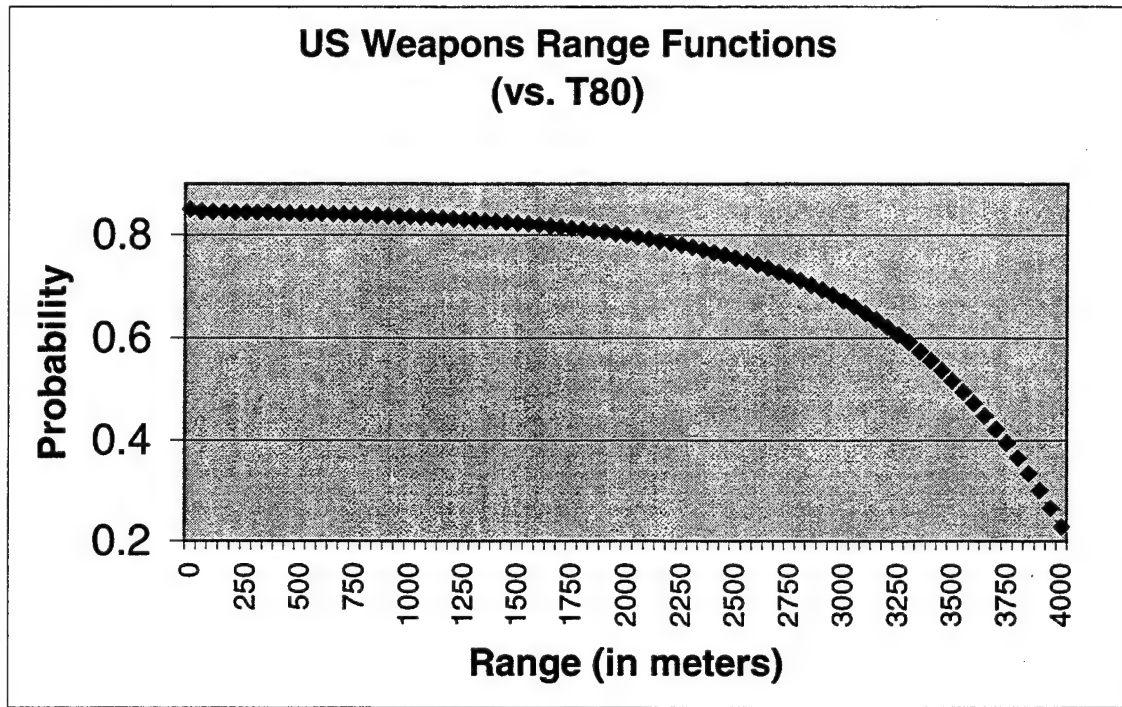
Figure 5. Hit & Kill Probabilities

C. SIMULATION CLASSES

Now that the algorithms and methods have been examined for each stage of the conduct of fire process, these algorithms and methods must be tied together to specific classes in the BCIS simulation model. Table 5 provides a reference list of classes and each of the algorithms or methods used by each of the classes. The Simkit source code for the *Acquire* class is in APPENDIX D, and the Simkit source code for the *BCISCheck* class is in APPENDIX E.

Algorithm & Method	Simkit Simulation Class
Line of Sight	*LOSCheck.getLineOfSight()*
ACQUIRE (for Detection)	*Acquire* class, also uses *Atmosphere* class
Identification	*BCISCheck* class - 3 methods *noBCIS()* - also uses *Acquire* class *onlyBCISID()* - also uses *Acquire* class *fullBCISSA()*- also uses *Acquire* class
Target Classification	*MostDangerousTarget()* - in *M1BasicSensor* class
Target Engagement - includes engagement sequence times and hit probabilities	*doShoot()* - in *M1BasicSensor* class *doKill()* - in *M1BasicSensor* class

Table 5. Algorithm/Method Reference List

D.   SCENARIO DESIGN

Realistic scenarios were developed to test each of the types of BCIS. The

scenarios involved M1A1 main battle tanks in company sized units executing a hasty

defense and a movement to contact against Russian style weapons.

1.   Force Structure

a.   *Systems*

All systems modeled in the simulation represented the characteristics of

military armored vehicles currently in service around the world. Unclassified data from

these systems were used in the model as system parameters [Ref. 18]. The U.S. systems

represented and available to the analyst are the M1A1 Abrams Main Battle Tank (MBT),

M2A3 Bradley Infantry Fighting Vehicle (IFV), and the M113A3 Armored Personnel

Carrier (APC). The Abrams and the Bradley both have similar fire control system

parameters. Both use a DVO sensor with 30% transmission as represented in the

ACQUIRE algorithm and BCIS operates identically on both vehicles so the differences in

this comparison are minor. For purposes of analysis a homogenous force of M1A1s was

44

used in the scenarios used to collect BCIS performance data. Only friendly systems are modeled for potential fratricide.

The enemy systems represented in the model consisted of current Russian armored vehicles. Many third world nations that could be in conflict with the United States or our allies use Russian style systems. The model provides the analyst with representations of the T-80U main battle tank, BMP-2 tracked IFV, BTR-80A wheeled IFV, and the BMD-2 airborne variant of the BMP-2. The parameters for these systems are all collected from open sources [Ref. 18]. Again, for purposes of analysis a homogenous force of T-80Us was used in the scenarios used to collect BCIS performance data.

BCIS data was collected using homogenous systems for both friendly and enemy forces. Use of other vehicles for both friendly and enemy forces requires a more sophisticated algorithm for modeling the weapons effects of various types of weapons systems. Keeping the test scenarios to a strict tank on tank duel negates the requirement to analyze weapons effects and allows this model to focus on target identification and BCIS performance. For instance, tanks from both sides can be hit by friendly machine gun fire but continue to operate, potentially unaware of the friendly fire. Capturing these different types of weapons effects is beyond the scope of this model. Additionally, the models uses engagement times and hit and kill probabilities from M1A1 gunneries that do not accurately represent the weapons systems performances of the IFVs and APCs represented in the model. The additional weapons systems represented in the model are

45

provided for future research and could be used in future scenarios with a weapons effects algorithm.

b.   *Organization*

The main size force used in both test scenarios is the tank company. In both cases it consists of three platoon sized units of four tanks apiece. The Russian style organization has an additional tank for the company commander, the US organization has two headquarters tanks. Thus, the enemy tank company has 13 tanks, the friendly tank company has 14. There are additional friendly and enemy platoon elements that enter into each of the scenarios. These elements are not as strictly controlled as the other two tank companies, and their unpredictable behavior is what creates potential incidents of fratricide. Other combat multipliers such as air support, engineers and artillery are not represented. Fratricide between air and ground systems is an important issue, but not addressed in this thesis.

2.   MISSIONS

The two scenarios that were chosen for the US force represent the two main types of maneuver, offensive and defensive operations. In each case, forces were placed into a situation where a lack of situational awareness has significantly increased the chances of fratricide. Both missions involve fluid situations and movements of friendly forces across lines of fire either deliberately or accidentally through poor understanding of situational awareness.

a. Movement To Contact

A movement to contact is an offensive operation designed to regain contact with the enemy. Usually it is conducted when knowledge about the enemy is required to plan future operations or friendly forces are looking to exploit enemy weakness. Because the enemy situation is unknown, the friendly force tries to make contact with the smallest element possible. Once contact is made friendly forces mass combat power onto perceived enemy weak points, attempting to create a penetration of enemy forward units [Ref. 19:p. 3-4].

In the model's movement to contact scenario, A Company, 3-64 Armor, is conducting a movement to contact to Objective Red, along Avenue of Advance Gold, to make contact with an enemy forward detachment (See Figure 6). The enemy tank company, reinforced with an additional tank platoon is acting as a forward detachment for their regiment. During A Company's movement, two platoons from B Company to their east move into A Company's sector. At the same time the enemy forward detachment appears and the platoons from B Company are caught between the two forces. This scenario illustrates the three main failures of situational awareness outlined in Chapter 1. The platoons from B Company have exhibited poor maneuver control by moving out of their assigned sector. A battle tracking failure exists on the part of two B Company platoon leaders, their commander, and perhaps even the battalion operations center. If any of the leaders in this organization had been aware of the problem they should have immediately cross talked with the other units in the battalion to make them aware of the problem and prevent a potential fratricide incident. Finally, both A

Company and B Company have had a breakdown in direct fire control measures and target identification. In this scenario there are 22 friendly vehicles (56.4% of the total forces involved), and 17 enemy vehicles (43.6% of the total forces involved).
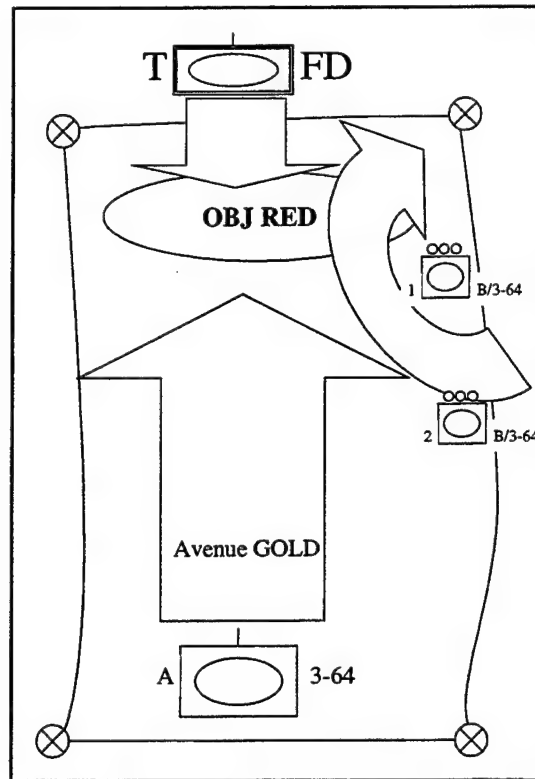
Figure 6. Movement To Contact Scenario

b. *Hasty Defense*

A hasty defense is an operation designed to defeat the enemy's attack and allow friendly forces to regain the initiative and resume offensive operations [Ref. 19:p. 4-3]. It is usually conducted when the enemy has gained the initiative in a particular sector or has achieved local superiority in combat power. The friendly force tries to destroy the enemy's reconnaissance, then allow the enemy to move into the friendly kill

48

zone. The term hasty implies that the friendly force has not had time to prepare extensive obstacles or fighting positions prior to the arrival of the enemy force.

In the model's hasty defense scenario, A Company, 3-64 Armor, is conducting a hasty defense at Battle Position Red, to destroy the enemy forward detachment (See Figure 7). A Company did not have time to dig prepared positions or emplace any obstacles. The enemy tank company, reinforced with an additional tank company, is acting as a forward detachment for their regiment. During A Company's defense, two platoons from B Company have been positioned forward to destroy enemy reconnaissance vehicles. B Company's platoons are supposed to withdraw along routes to the east and west of Battle Position Red. The enemy has spotted their withdrawal and has accelerated their advance. As A Company prepares to destroy the advancing enemy forces, B Company's withdrawing platoons became mixed with the enemy advance. Again, this scenario illustrates the three main failures of situational awareness outlined in Chapter 1, poor maneuver control, direct fire control failures, and battle tracking failures. The platoons from B Company exhibit poor maneuver control by straying from their assigned routes. They should have maintained a communication link with A Company and conducted the required coordination and cross talk when they realized the enemy force was moving more rapidly than expected. Finally, as with the movement to contact scenario, both A Company and B Company have a total breakdown in direct fire controls and target identification. In this scenario there are 22 friendly vehicles (42.3% of the total forces involved), and 30 enemy vehicles (57.7% of the total forces involved).
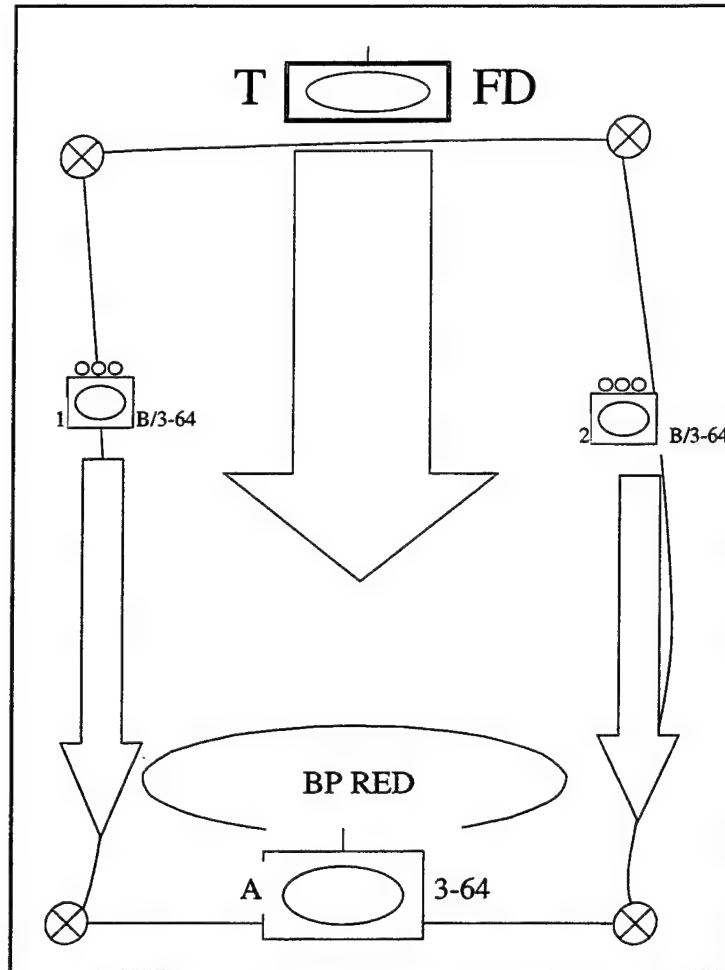
Figure 7. Hasty Defense Scenario

E. MODEL VERIFICATION AND VALIDATION

Verification and validation ensure that a simulation model works as designed and

provides reasonable results. Verification is the determination that computer programs

and algorithms match their intended use and do not contain mathematical or logical

errors. Validation is the comparison of the model results with real world objects,

systems, or processes that it represents. Validation can refer to proper representation of

specific systems or processes in the model or can be used to gauge the model's ability to

50

predict the outcome or behavior of a system [Ref. 20:p. 300-317]. Both verification and validation are time consuming processes that may not be entirely attainable.

Part of the focus of this thesis was to explore ways that situational awareness and target identification systems can be modeled. This study developed a tool for further analysis of these types of systems and identified some of the challenges in representing these systems, and some of the assumptions that were made to ensure a faithful representation of the system processes in the model.

Efforts were made to verify the algorithms used and source code that was written for this model. Logical and computation verification of the model was tested during the development of this model by developing logical flowcharts and testing computations wherever possible by both the author and the advisors. Detailed scenarios were used to further test and stress the algorithms and logic used in the model. Mover and sensor positions were plotted against each other as detection and engagements occurred to verify range and location calculations. Logic checks were printed out at each step on the algorithms to verify correct values were used and correct tests were being conducted. A high degree of confidence is associated with the model verification.

Model validity is a more difficult task. The algorithms and methods chosen to represent processes in the model are both generally accepted and widely used for the same purpose in other models. The ACQUIRE algorithm used in the BCIS model is the accepted standard used by the Army Modeling and Simulation Office for target detection models [Ref. 16]. System parameters for other algorithms are derived from documented sources and accepted references. Finally, several independent discussions were

51

conducted with fratricide and gunnery system subject matter experts to ensure proper representation of the processes involved. While this model cannot be considered validated, it does appear to give reasonable results.

F.   MEASURES OF PERFORMANCE

The purpose of this thesis is to answer the question: Does the Battlefield Combat Identification System improve combat effectiveness, defined as increased lethality and reduction in fratricide. We have identified the object components of the model, studied the specific model processes, and developed the basic scenarios. The following measure of performance (MOPs) will be used to evaluate each of the components of combat effectiveness for the tank company during the simulation runs.

MOP #1: Loss exchange ratio (LER). The LER is defined as the number of enemy vehicles destroyed to number of friendly vehicles destroyed (by both sides). The LER provides a measure of lethality after increasing the level of situational awareness and improving target identification capability.

MOP #2: Fratricide ratio. Fratricide ratio is defined as the number of fratricide incidents to the number of vehicles destroyed by friendly forces (both friendly and enemy). The fratricide ratio will provide a measure of fratricide incidents after increasing the level of situational awareness and improving target identification capability.

Table 6 shows how the simulation data will be collected for each mission.

Level of SA and Target ID (Independent Variable)	Combat Effectiveness (Dependent Variable)	
	Lethality	Fratricide
No BCIS (No ID or SA)	MOE #1 – LER	MOE #2 – Fratricide ratio
BCIS w/o DDL (ID, no SA)	MOE #1 – LER	MOE #2 – Fratricide ratio
BCIS w/ DDL (ID and SA)	MOE #1 – LER	MOE #2 – Fratricide ratio

Table 6. Experiment Design by Mission

V. RESULTS & ANALYSIS

A.   TOOLS FOR ANALYSIS

Statistical analysis for comparing the mean values of the different BCIS variants was conducted by an analysis of variance (ANOVA). In this case a single factor or single classification ANOVA was conducted to determine if the samples come from a population with the same mean value, thus hypothesis was

$$H_o : \mu_{noBCIS} = \mu_{BCIS} = \mu_{BCISDDL} = \mu .$$

The test procedure for the ANOVA consists of testing a ratio of the difference among the sample means, mean square for treatments, to the variation within the sample, mean square for error. The test statistic is compared to the value of the F-distribution with degrees of freedom equal to v_1 and v_2. For all of the comparisons these values are:

$$v_1 = \# BCIS \; variants - 1 = 2$$

$$v_2 = \# BCIS \; variants * (\# Observations - 1) = 297$$

The test statistic is then compared to the critical value for the ANOVA, and the null hypothesis is rejected if

$$f \geq F_{\alpha, 2, 297} .$$

The test was conducted using SPLUS 4.0, which calculates the f statistic and the resulting p-value at the calculated f statistic. The level of statistical significance chosen for these tests was $\alpha = 0.05$. This is the value that is normally used to determine statistical significance [Ref. 21:p. 333]. Based on this level of statistical significance, H_o was rejected if the p-value ≤ 0.05. [Ref. 21:p. 390-400].

55

The results of the ANOVA only highlight if there is a significant difference in the population means. If the null hypothesis is rejected, ANOVA results do not indicate which of these population means are different and another test must be used to highlight which means differ from each other. The Tukey method is used to conduct specific comparisons of different variants of BCIS. The Tukey method is used to conduct multiple comparisons based on the Studentized range distribution. This method computes a collection of simultaneous confidence statements about the true differences in each of the MOP population means with each of the BCIS variants [Ref. 21:p. 400-404].

B.   SIMULATION RESULTS

Table 7 shows the results of the simulation runs for the movement to contact mission for each of the MOPs.

Level of SA and Target ID	Combat Effectiveness (Dependent Variable)	
(Independent Variable)	Lethality	Fratricide
No BCIS (No ID or SA)	.8928	.1525
BCIS w/o DDL (ID, no SA)	1.0253	.0209
BCIS w/ DDL (ID and SA)	1.1455	.0076

Table 7. Results for Movement To Contact

Table 8 shows the results of the simulation for the hasty defense mission for each of the MOPs.

Level of SA and Target ID	Combat Effectiveness (Dependent Variable)	
(Independent Variable)	Lethality	Fratricide
No BCIS (No ID or SA)	.6332	.3989
BCIS w/o DDL (ID, no SA)	.9034	.1114
BCIS w/ DDL (ID and SA)	.8784	.1182

Table 8. Results for Hasty Defense

The raw data for the results of both simulations is included in APPENDIX A.

C.   ANALYSIS OF RESULTS

The results of applying the ANOVA described above to the results of the simulation for each of the two scenarios are displayed below. For each of the hypotheses, the p-value result represents whether H_o was rejected or accepted. In all cases, if the p-value is less than 0.05, H_o was rejected and it can be concluded that there exists a significant difference between the two or more of the population means. For each case where Ho was rejected, the Tukey method was applied to determine where the specific differences were.

For the Movement to Contact scenario results of the ANOVA are:

Variables	Degrees of Freedom	Sum of Squares	Mean of Squares	F Value	P-Value
BCIS Levels	2	3.1957	1.5979	1.6059	0.2025
Residuals	297	2	0.995021		

Table 9. ANOVA Results for Movement to Contact LER

Variables	Degrees of Freedom	Sum of Squares	Mean of Squares	F Value	P-Value
BCIS Levels	2	1.2827	0.6414	132.1404	0.0
Residuals	297	1.4416	0.0049		

Table 10. ANOVA Results for Movement to Contact Fratricide Ratio

The results of the movement to contact scenario showed that there was no significant different in the LER ratio for the different variants of BCIS. It did not increase the lethality of the units using it. This result seemed non intuitive and further examination was required to determine the cause of this result. One of the 100 scenario runs used to collect the data from the BCIS DDL resulted in a LER of 17.0. Only one friendly vehicle was destroyed and all 17 of the enemy vehicles were destroyed. In the remaining 99 scenario runs the next highest LER was 2.28. The LER of 17.0 clearly represents an outlier, which increases the sample standard deviation enough to potentially affect the results of the ANOVA. Conducting the same analysis without the data point results in significant difference between the LERs. Table 11 shows the p-value without the outlier data.

	Means	Standard Deviations	p-value	Significant
With Run #11	1.1455	1.6403	0.2025	NO
Without Run #11	0.9854	0.3568	0.0454	YES

Table 11. Data Anomaly For Movement To Contact Scenario

Although the mean is reduced, the large change in the standard deviation affects the ANOVA enough to now reject the null hypothesis. The conclusion is that the single data point represents an anomaly and a significant difference exists between the lethality of a unit equipped with different BCIS variants.

Examining the results of the Tukey method with out this outlier is shown in Figure 8.
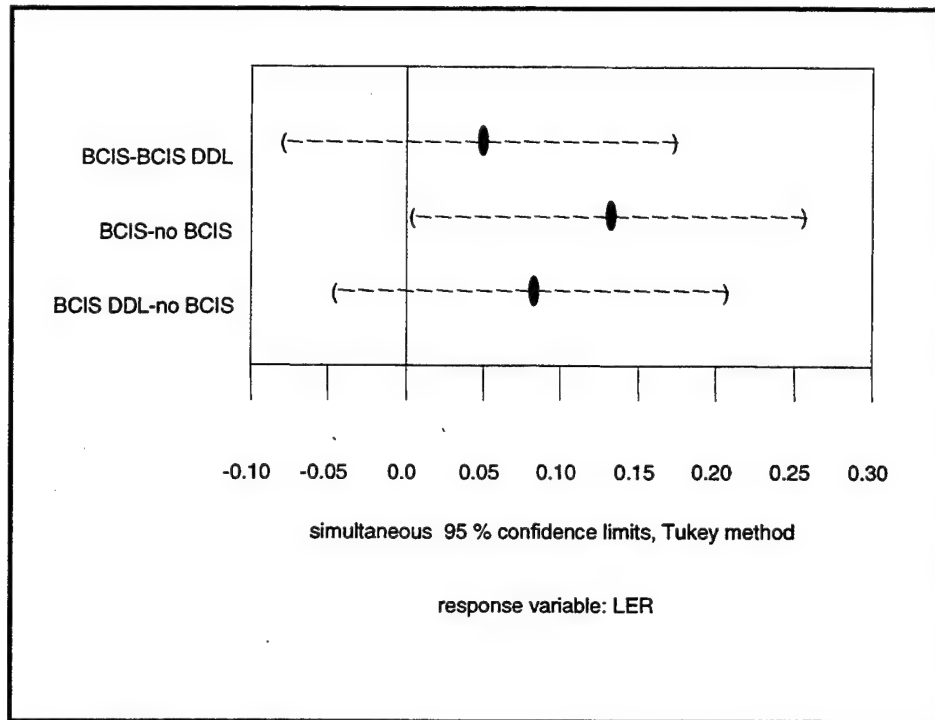
Figure 8. **Tukey Method Results for Movement to Contact LER**

This figure shows that there is a significant increase between the lethality of a unit

equipped with BCIS and without BCIS because the confidence interval for this

comparison does not include zero. BCIS DDL fails to provide a significant advantage

over BCIS or a non-BCIS equipped unit. The extra time required to correlate the

situational awareness data has a detrimental effect on the unit's lethality and causes a

lower LER.

For the second MOP, fratricide ratio, there was a significant difference in the

MOP between all three levels of BCIS. The results of the Tukey method are shown in

Figure 9.

59
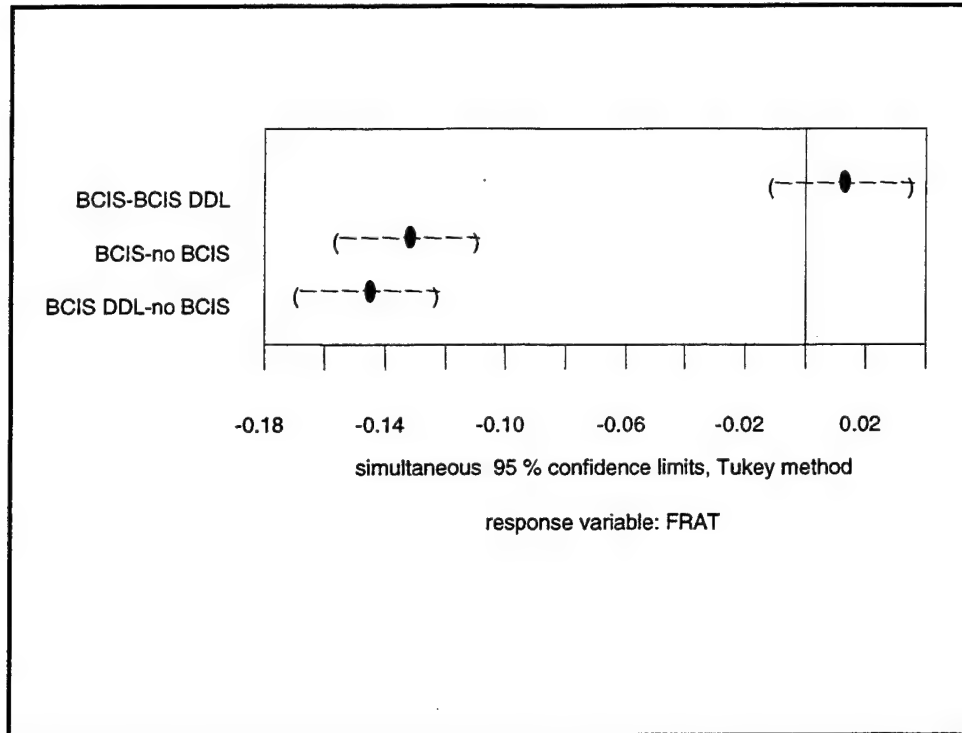
Figure 9. Tukey Method Results for Movement to Contact Fratricide Ratio

The fratricide ratio fell from 15.25% in the scenarios without BCIS to 2.09% with the baseline version of BCIS and to 0.76% for the BCIS DDL. Based on the Tukey results, both BCIS and the BCIS DDL provide a decrease in fratricide over a unit that is not equipped with BCIS. BCIS DDL provides no decrease over the baseline BCIS.

For the Hasty Defense Scenario results of the ANOVA are:

Variables	Degrees of Freedom	Sum of Squares	Mean of Squares	F Value	P-Value
BCIS Levels	2	4.4571	2.2286	15.4128	0.0
Residuals	297	42.9439	0.1446		

Table 12. ANOVA Results for Hasty Defense LER

Variables	Degrees of Freedom	Sum of Squares	Mean of Squares	F Value	P-Value
BCIS Levels	2	5.3173	2.6586	277.7232	0.0
Residuals	297	2.8432	0.0096		

Table 13. ANOVA Results for Hasty Defense Fratricide Ratio

For the hasty defense scenario similar results were achieved for both MOPs. In both cases there was a significant difference in population means between each of the BCIS variants. Figure 10 shows the results of the Tukey method for the LER.
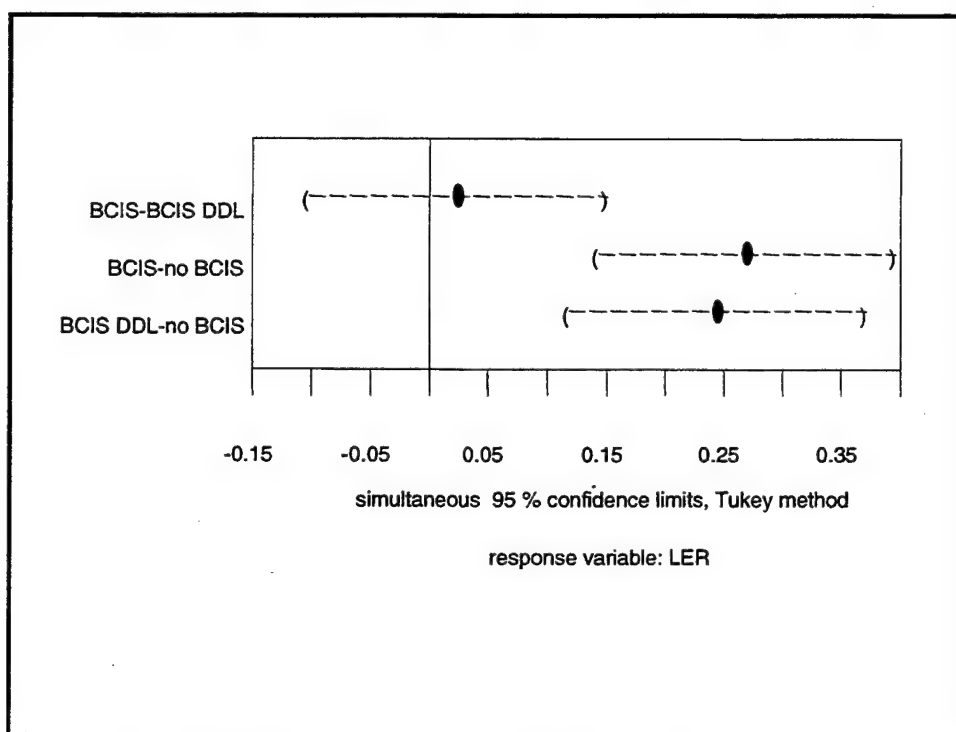
Figure 10. Tukey Method Results for Hasty Defense LER

The BCIS and BCIS DDL equipped units achieved a significant increase in LER over the non-BCIS equipped force. The BCIS DDL system did not achieve significance over the baseline BCIS for this MOP. For the defensive scenario, the impact of BCIS is much greater on the unit's lethality than in the movement to contact scenario.

61

For the fratricide ratio Figure 11 shows the results of the Tukey comparison.
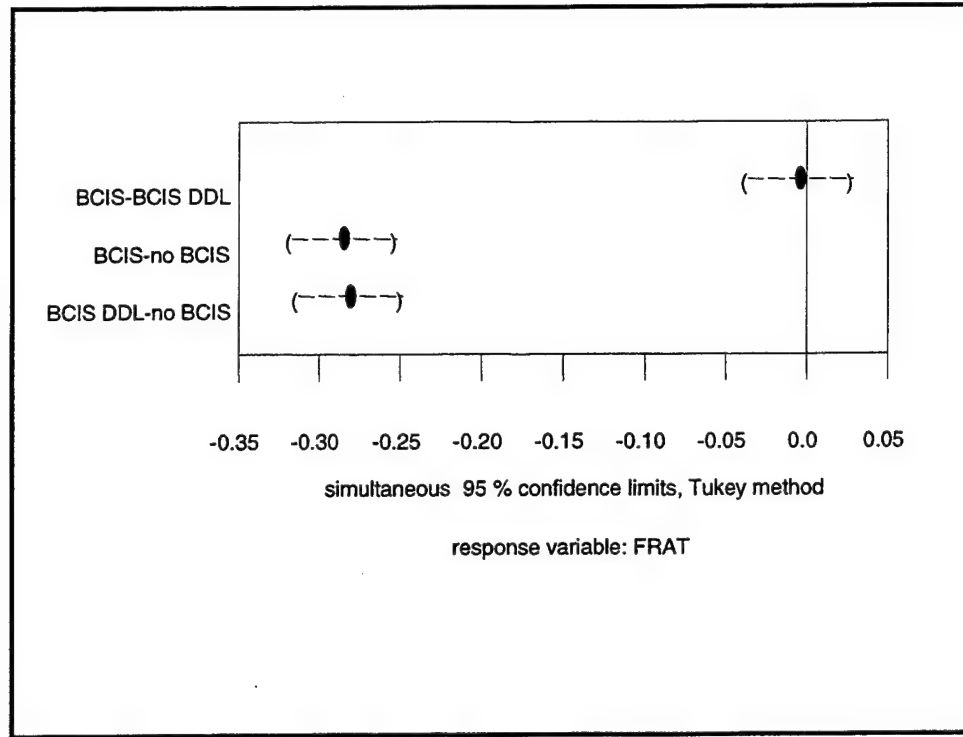
Figure 11. Tukey Method Results for Hasty Defense Fratricide Ratio

Again, it is clear here that both variants of BCIS provide a significant decrease in the number of fratricide incidents over the non-BCIS equipped units. The BCIS DDL system again did not achieve significance over the baseline BCIS for this MOP. Results of the ANOVA and the results of the Tukey method are shown for both scenarios in APPENDIX C.

It is not conclusive from this analysis that a target identification system with a situational awareness package can increase combat effectiveness. In the movement to contact scenario it did not show an increase in the LER by a significant amount. The BCIS DDL did not demonstrate a significant improvement over the baseline BCIS in any of the other cases.   This result indicates that the extra time required to correlate

situational awareness information with the current battlefield situation reduces the effectiveness of the situational awareness system. Intuitively, it is expected that a situational awareness system should increase lethality by reducing the overall number of unknown targets that must be examined and fired upon by the crew. This lethality increase is balanced by the additional time required for the crew to correlate the situational awareness appliqué information with what is being observed.

Another reason this and other studies have not been able to show an improvement with a situational awareness system is the difficulty in modeling the benefits of this type of system [Ref. 9]. The benefits of a situational awareness system are most evident prior to either side beginning to engage the other. Examining the two scenarios used in the simulation from an operational perspective, it appears that a situational awareness system could have prevented the platoons from B Company from being engaged by friendly forces. In the Movement to Contact Scenario, B Company should have observed their situational awareness appliqué showing them entering A Company's sector. Those platoon leaders, their commander, or the battalion operations center should have observed the problem. It would also have been noted that A Company weapons systems had observed and were preparing to engage B Company. Similarly, in the Hasty Defense Scenario, a situational awareness appliqué would show the platoons from B Company that they were moving off planned withdrawal routes and into A Company's line of fire.

These examples only serve to highlight the fact that it is difficult to model the impacts of situational awareness. The primary impact of a situational awareness system is to reduce human errors. The simulation attempts to capture and model some human

63

errors and imperfect maneuver that is inherent in any Army operation. The impact of the situational awareness appliqué on human behavior must also be modeled. Modeling human errors in a simulation can be difficult, but it is even more difficult to model the effect of an information system and how it will impact the decision process to reduce these errors. Currently we do not have enough experience with these systems to accurately determine how to correctly predict the behavior of the soldiers using them. The BCIS simulation model forces the objects in the simulation to check the situational awareness information and assumes the object, in this case the vehicle crew, will make the correct decisions with the given information.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The results of this simulation show that a target identification system can positively increase the combat effectiveness of a tank company. Modern armored combat is a fluid, rapidly paced series of duels at the small unit level. With the lethality of the weapons systems being used today, it is clear that whichever side has the most knowledge about the battlefield will be able to seize the initiative and likely win the engagement. Winning the engagement means surviving, destroying the enemy, and being more combat effective. The answer to the Joint Staff's question of how BCIS impacts doctrine and force structure is that it increases combat effectiveness by increasing lethality and reducing fratricide. Increased combat effectiveness means our forces can move more rapidly, react more quickly, and apply dominant maneuver and precision engagement to the battlefield.

This thesis determined the effectiveness of BCIS and provided a simulation model for determining how to represent BCIS and BCIS variants. The model can be used to further test BCIS or to test other methods for modeling situational awareness or target identification systems. The model also provides insight into the effect of these types of systems at the small unit level.

Conclusions from this research are that identification and situational awareness systems such as BCIS narrow the tradeoff between engaging targets at extended ranges and the ability to correctly identify targets. Units should be equipped with BCIS since

they will be more lethal and less likely to commit fratricide than non-BCIS equipped units.

B.   RECOMMENDATIONS FOR FURTHER RESEARCH

Further research is necessary in this area. More comprehensive research is required to determine the causes of fratricide, and derive solutions for situational awareness and target identification issues. All of these areas involve the study of human decision making, particularly decision making in combat.

The BCIS simulation model captures the characteristics of BCIS and provides a tool for analysis for similar studies. As more information becomes available about BCIS capabilities, the model can be further refined to reflect improvements in the system. Also, the BCIS simulation model used in this study is based on an implicit representation of the terrain. An explicit terrain representation would provide better insights as to how the system would perform under a broader range of terrain conditions.

Situation awareness is an area that needs considerably more study. What is the best way of presenting information to the soldier in combat? What information is needed and how should it be presented in order to be most beneficial? The problem of developing a tool to assist in decision making and to provide information for all users is difficult. As with any other system that provides information, the system is only as good as the training and the doctrinal solutions to employ the system.

Additional questions remain as to how should human behavior and decision making be modeled to represent a situational awareness appliqué in a simulation. The

appliqué provides situational awareness information, but whether the operator maneuvers smarter based on this information is a function of training, leadership, and competency.

Finally, additional research is needed to explore the integration of such systems across services or between military coalitions. Research should continue to advance technologies and capabilities across branches of service and national alliances. Joint and coalition operations inherently contribute to situational awareness problems, and systems such as BCIS become even more vital to reduce fratricide and improve situational awareness.

APPENDIX A. SIMULATION RESULTS

MOVEMENT TO CONTACT RESULTS

Movement to Contact (No BCIS) LER		Movement to Contact (No BCIS) Frat Ratio	
Mean	0.8928	Mean	0.1525
Standard Error	0.0263	Standard Error	0.0115
Median	0.8819	Median	0.1579
Mode	1.0000	Mode	0.0000
Standard Deviation	0.2629	Standard Deviation	0.1151
Range	1.1818	Range	0.4375
Minimum	0.3636	Minimum	0.0000
Maximum	1.5455	Maximum	0.4375
Movement to Contact (BCIS) LER		**Movement to Contact (BCIS) Frat Ratio**	
Mean	1.0253	Mean	0.0209
Standard Error	0.0475	Standard Error	0.0030
Median	0.9333	Median	0.0000
Mode	1.0000	Mode	0.0000
Standard Deviation	0.4746	Standard Deviation	0.0302
Range	4.0227	Range	0.1111
Minimum	0.2273	Minimum	0.0000
Maximum	4.2500	Maximum	0.1111
Movement to Contact (BCIS DDL) LER		**Movement to Contact (BCIS DDL) Frat Ratio**	
Mean	1.1455	Mean	0.0076
Standard Error	0.1640	Standard Error	0.0020
Median	0.8889	Median	0.0000
Mode	0.7895	Mode	0.0000
Standard Deviation	1.6403	Standard Deviation	0.0198
Range	16.7273	Range	0.0625
Minimum	0.2727	Minimum	0.0000
Maximum	17.0000	Maximum	0.0625

HASTY DEFENSE RESULTS

Hasty Defense (No BCIS) LER		Hasty Defense (No BCIS) Frat Ratio	
Mean	0.6332	Mean	0.3987
Standard Error	0.0289	Standard Error	0.0123
Median	0.6283	Median	0.3798
Mode	0.6667	Mode	0.5000
Standard Deviation	0.2893	Standard Deviation	0.1228
Range	1.8800	Range	0.6026
Minimum	0.1200	Minimum	0.1667
Maximum	2.0000	Maximum	0.7692
Largest(1)	2.0000	Largest(1)	0.7692
Smallest(1)	0.1200	Smallest(1)	0.1667

Hasty Defense (BCIS) LER		Hasty Defense (BCIS) Frat Ratio	
Mean	0.9034	Mean	0.1144
Standard Error	0.0427	Standard Error	0.0087
Median	0.8650	Median	0.0984
Mode	0.8000	Mode	0.0000
Standard Deviation	0.4274	Standard Deviation	0.0868
Range	2.3519	Range	0.4545
Minimum	0.1481	Minimum	0.0000
Maximum	2.5000	Maximum	0.4545
Largest(1)	2.5000	Largest(1)	0.4545
Smallest(1)	0.1481	Smallest(1)	0.0000

Hasty Defense (BCIS DDL) LER		Hasty Defense (BCIS DDL) Frat Ratio	
Mean	0.8784	Mean	0.1182
Standard Error	0.0409	Standard Error	0.0078
Median	0.8000	Median	0.1017
Mode	0.7500	Mode	0.0000
Standard Deviation	0.4092	Standard Deviation	0.0781
Range	2.1008	Range	0.4000
Minimum	0.2069	Minimum	0.0000
Maximum	2.3077	Maximum	0.4000
Largest(1)	2.3077	Largest(1)	0.4000
Smallest(1)	0.2069	Smallest(1)	0.0000

70

APPENDIX B. BCIS SIMULATION MODEL FLOWCHARTS

The following figures are a detailed representation of how the conduct of fire

process is modeled in each of the three cases, without BCIS, with BCIS, and with BCIS

DDL.
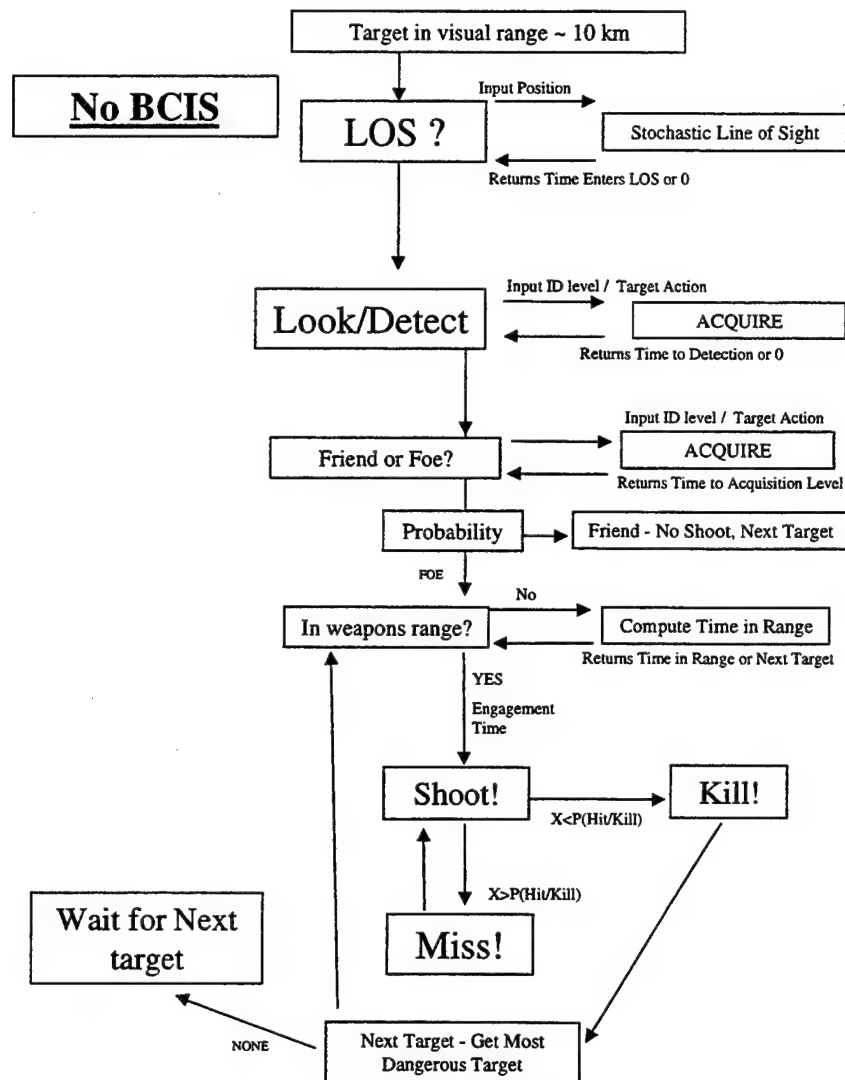
Figure 12. Engagement Model without BCIS
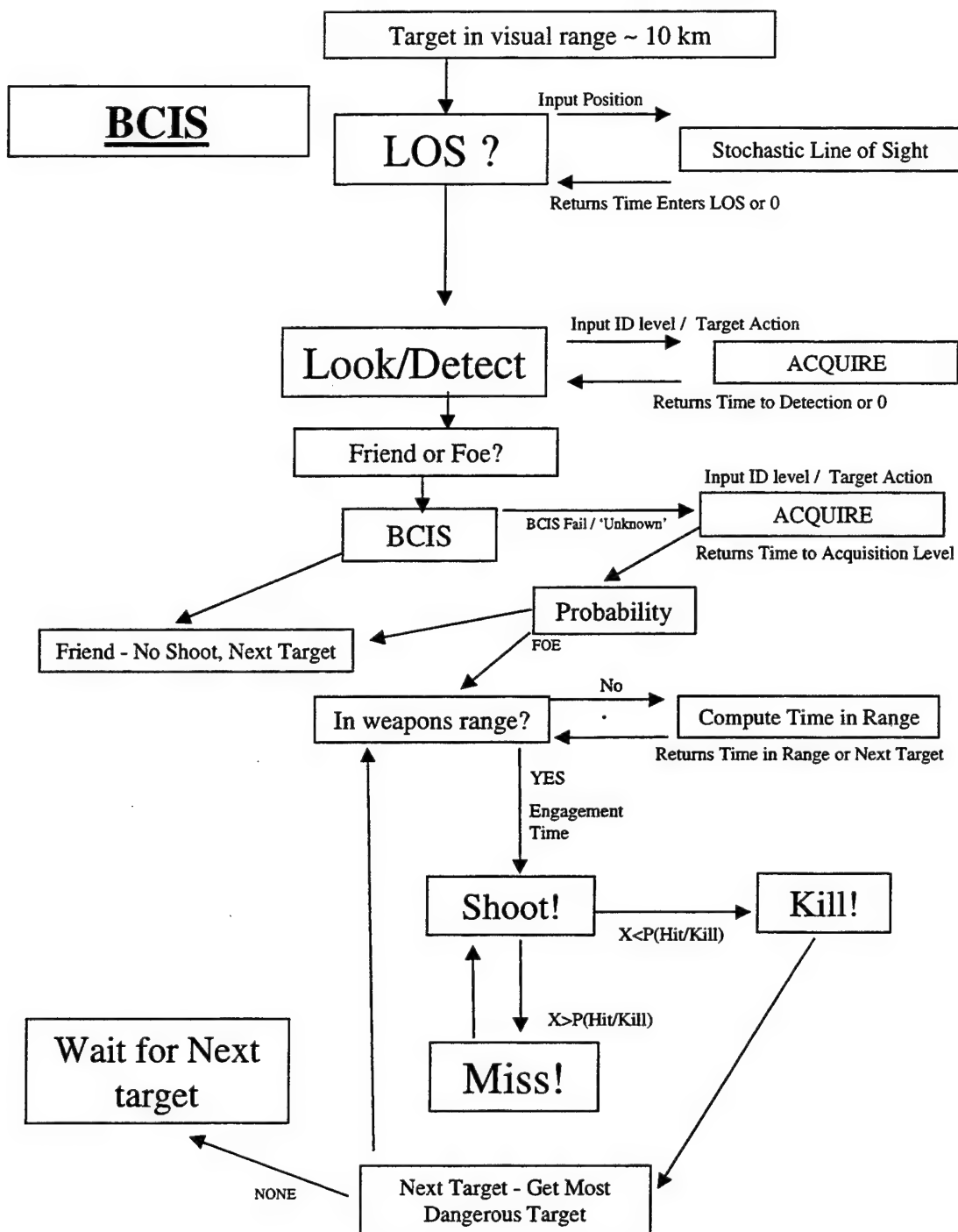
Figure 13. Engagement Model with BCIS

BCIS DDL

Target in visual range ~ 10 km

LOS ?

Input Position →

Stochastic Line of Sight

← Returns Time Enters LOS or 0

Look/Detect

Input ID level / Target Action →

ACQUIRE

← Returns Time to Detection or 0

Friend or Foe?

BCIS

BCIS Fail / 'Unknown' →

Input ID level / Target Action

ACQUIRE

Returns Time to Acquisition Level

Probability

Friend - No Shoot, Next Target

FOE

In weapons range?

No →

Compute Time in Range

← Returns Time in Range or Next Target

YES

Engagement Time

Send DDL Situational Awareness Message

Shoot!

X<P(Hit/Kill) →

Kill!

X>P(Hit/Kill)

Miss!

Wait for Next target

NONE

Next Target - Get Most Dangerous Target

Check Situational Awareness Appliqué for updates

Figure 14. Engagement Model with BCIS DDL

APPENDIX C. ANOVA RESULTS

Movement to Contact ANOVA / Tukey Results for LER with outlier:

```
***   One-Way ANOVA for data in LER by V1 ***

Call: aov(formula = structure(.Data = LER ~ V1, class = "formula"),
data = MTCLERA)

Terms:
                      V1  Residuals
 Sum of Squares   3.1957  295.5211
Deg. of Freedom        2       297
Residual standard error: 0.9975072
Estimated effects are balanced

          Df Sum of Sq  Mean Sq  F Value      Pr(F)
      V1   2    3.1957 1.597868 1.605864 0.2024538
Residuals 297  295.5211 0.995021

95 % simultaneous confidence intervals for specified
linear combinations, by the Tukey method
critical point: 2.3555
response variable: LER

intervals excluding 0 are flagged by '****'
                Estimate Std.Error Lower Bound Upper Bound
    BCIS-BCIS DDL  -0.120     0.141    -0.4530       0.212
     BCIS-no BCIS   0.133     0.141    -0.2000       0.465
 BCIS DDL-no BCIS   0.253·    0.141    -0.0796       0.585
```

Movement to Contact ANOVA / Tukey Results for LER without outlier:

```
***   One-Way ANOVA for data in LER by V1 ***

Call: aov(formula = structure(.Data = LER ~ V1, class = "formula"),
data = MTCLERA)

Terms:
                      V1  Residuals
 Sum of Squares   0.8959   42.5783
Deg. of Freedom        2       297
Residual standard error: 0.3786308
Estimated effects are balanced

          Df Sum of Sq   Mean Sq  F Value      Pr(F)
      V1   2    0.8959 0.4479514 3.124633 0.04540132
Residuals 297  42.5783 0.1433613
```
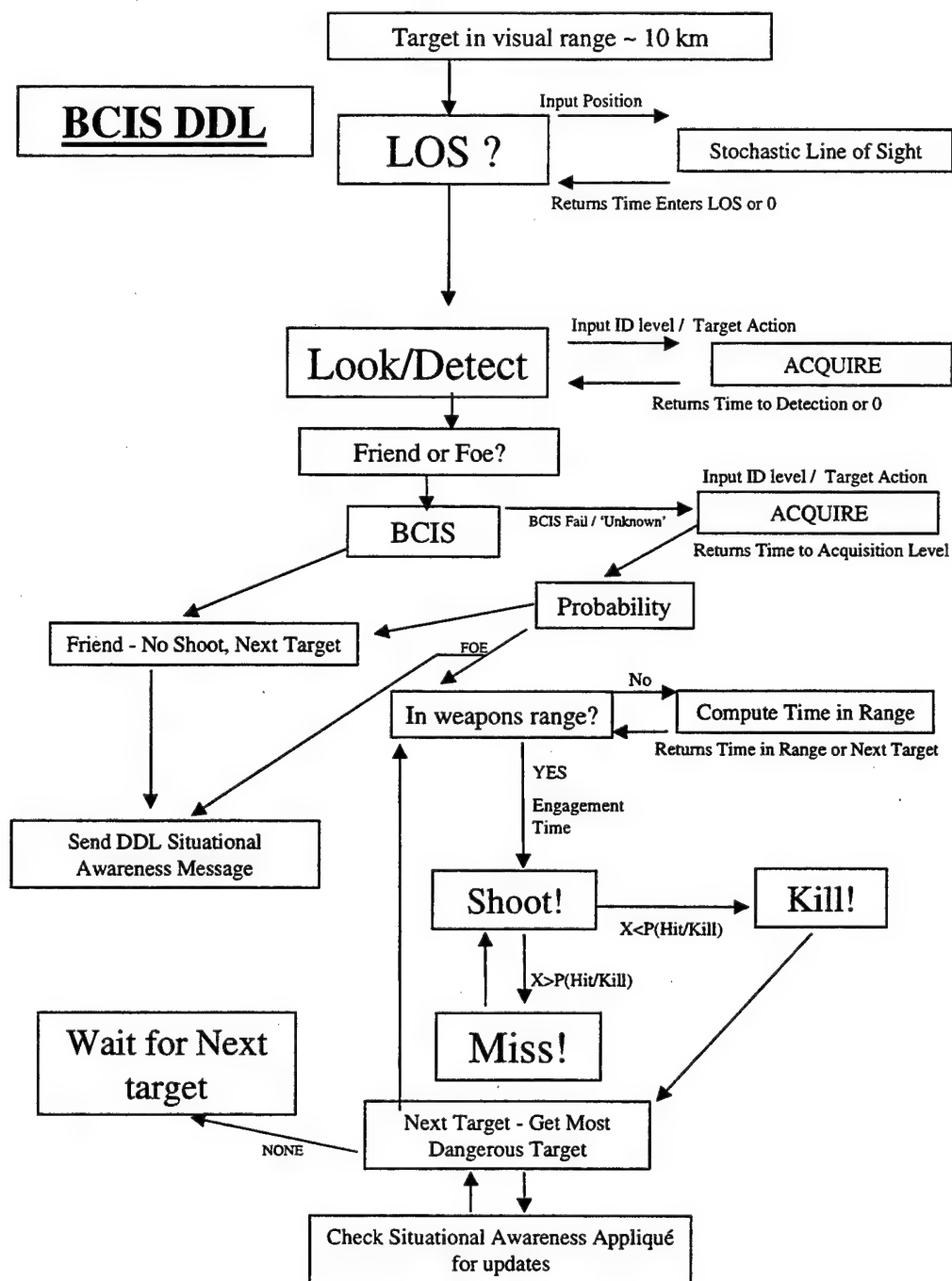
75

```
95 % simultaneous confidence intervals for specified
linear combinations, by the Tukey method
critical point: 2.3555
response variable: LER

intervals excluding 0 are flagged by '****'
                  Estimate Std.Error Lower Bound Upper Bound
    BCIS-BCIS DDL   0.0498    0.0535    -0.07630      0.176
     BCIS-no BCIS   0.1330    0.0535     0.00637      0.259 ****
BCIS DDL-no BCIS    0.0827    0.0535    -0.04340      0.209
```

Movement to Contact ANOVA / Tukey Results for Fratricide Ratio:

```
        ***   One-Way ANOVA for data in FRAT by V1 ***

Call: aov(formula = structure(.Data = FRAT ~ V1, class = "formula"),
data = MTCFRATA)

Terms:
                        V1 Residuals
 Sum of Squares 1.282742  1.441551
Deg. of Freedom        2       297
Residual standard error: 0.06966856
Estimated effects are balanced

          Df Sum of Sq   Mean Sq  F Value Pr(F)
       V1  2  1.282742 0.6413708 132.1404     0
Residuals 297  1.441551 0.0048537

95 % simultaneous confidence intervals for specified
linear combinations, by the Tukey method
critical point: 2.3555
response variable: FRAT

intervals excluding 0 are flagged by '****'
                  Estimate Std.Error Lower Bound Upper Bound
    BCIS-BCIS DDL   0.0133   0.00985    -0.00993      0.0365
     BCIS-no BCIS  -0.1320   0.00985    -0.15500     -0.1080 ****
BCIS DDL-no BCIS   -0.1450   0.00985    -0.16800     -0.1220 ****
```

Hasty Defense ANOVA / Tukey Results for LER:

```
        ***   One-Way ANOVA for data in LER by Defend ***

Call: aov(formula = structure(.Data = LER ~ Defend, class = "formula"),
data = defler)

Terms:
```

```
                Defend Residuals
 Sum of Squares  4.45714  42.94379
Deg. of Freedom       2       297
Residual standard error: 0.3802524
Estimated effects are balanced


         Df Sum of Sq  Mean Sq  F Value        Pr(F)
   Defend  2   4.45714 2.228572 15.41284 4.279077e-007
Residuals 297  42.94379 0.144592
```

95 % simultaneous confidence intervals for specified
linear combinations, by the Tukey method
critical point: 2.3555
response variable: LER

intervals excluding 0 are flagged by '****'

	Estimate	Std.Error	Lower Bound	Upper Bound	
BCIS-BCIS DDL	0.0249	0.0538	-0.102	0.152	
BCIS-no BCIS	0.2700	0.0538	0.143	0.397	****
BCIS DDL-no BCIS	0.2450	0.0538	0.119	0.372	****

Hasty Defense ANOVA / Tukey Results for Fratricide Ratio:

    *** One-Way ANOVA for data in FRAT by Defend ***

Call: aov(formula = structure(.Data = FRAT ~ Defend, class =
"formula"), data = deffrat)

Terms:
```
                Defend Residuals
 Sum of Squares 5.317258  2.843165
Deg. of Freedom      2       297
Residual standard error: 0.09784143
Estimated effects are balanced


         Df Sum of Sq  Mean Sq  F Value Pr(F)
   Defend  2   5.317258 2.658629 277.7232     0
Residuals 297  2.843165 0.009573
```

95 % simultaneous confidence intervals for specified
linear combinations, by the Tukey method
critical point: 2.3555
response variable: FRAT

intervals excluding 0 are flagged by '****'

	Estimate	Std.Error	Lower Bound	Upper Bound	
BCIS-BCIS DDL	-0.00382	0.0138	-0.0364	0.0288	
BCIS-no BCIS	-0.28400	0.0138	-0.3170	-0.2520	****
BCIS DDL-no BCIS	-0.28000	0.0138	-0.3130	-0.2480	****

APPENDIX D. ACQUIRE ALGORITHM SOURCE CODE

```java
import java.lang.*;
import java.util.*;
import simkit.data.*;
import simkit.*;
import simkit.smd.*;
import simkit.util.*;
/**
  * Mark V. Grabski <BR>
  * CID Thesis Project : Acquire <BR>
  * Comments: the ACQUIRE target acquision algorithm
**/
public class Acquire {
   //class variables
   public static double IdLevel= 2.0;
   public static RandomStream SightLine;
   static{SightLine = new RandomStream();}

   // class methods
public static double[] detectLevel(M1BasicMover target, M1BasicSensor
      sensor, Atmosphere battleF, int check, double IdLevel){
   double [] detection = new double[2];
   double contrast = 0.0;
   double spatialFreq = 0.0;
   double cycles = 0.0;
   double cycleRatio= 0.0;
   double infProb = 0.0;
   double avgTime = 0.0;
   Coordinate targetAt = new Coordinate(target.getCurrentLocation());
   double range = targetAt.distanceFrom(sensor.getCurrentLocation());
   if (Schedule.simTime()>=0 && Schedule.simTime()<=1800){
        battleF.setLight("DAY");
   }
   else { battleF.setLight("NIGHT");}
   int time = battleF.getLight();
   if (time == 1) {
      double transmittance = Math.exp(battleF.getAttenuation()*
```

```java
                    range+battleF.getObscurants());
        contrast =battleF.getTargetInContrast()/(1+
                (battleF.getBrightnessRatio()*(transmittance-1)));
    }
    else {
        double transmittance =Math.exp(battleF.getAttenuation()
                *range+battleF.getObscurants());
        contrast =battleF.getTargetInContrast()*transmittance;
    }
    spatialFreq = battleF.getSpatialFreq(contrast,time);
    cycles= spatialFreq*sensor.getMag(check, time)*Math.sqrt(target.
            getFrontArea())/range;
    cycleRatio = cycles*target.getAction() / IdLevel;
    infProb = Math.pow(cycleRatio,0.7*cycleRatio+2.7)/(1+
            Math.pow(cycleRatio,0.7*cycleRatio+2.7));
    double probDetect = SightLine.uniform();
    if (infProb <= 0.9) {
        avgTime = 3.4*((1.04779*2.0)/sensor.getSightWidth(check,
                time))/infProb;
    }
    else {
        avgTime = 6.8*((1.04779*2.0)/sensor.getSightWidth(check,
                time))/cycleRatio;
    }
    if (probDetect <= infProb){
        detection[0]= (-avgTime*(Math.log(1-(probDetect/infProb))))/60;
        detection[1]= sensor.getIdLevel();
    }
    else {
        detection[0]= (avgTime*2)/60;
        detection[1]= sensor.getIdNum();
    }
    return detection;
    }
}
```

APPENDIX E. BCIS METHODS SOURCE CODE

```
public static double[] noBCIS(M1BasicMover target, M1BasicSensor
   sensor) {
   double [] identification = new double[3];
   double[] IDlowMag = Acquire.detectLevel(target, sensor,
      sensor.getAtmosCond(), 1, sensor.getIdLevel());
   double[] IDhighMag = Acquire.detectLevel(target, sensor,
      sensor.getAtmosCond(), 2, sensor.getIdLevel());
   double blueProb=((.95 - getBluePer())/3)*(sensor.getIdNum()-
      1)+getBluePer();
   double redProb = ((.95 - getRedPer())/3)*(sensor.getIdNum()-
      1)+getRedPer();
   if (((M1BasicMover)sensor.getMoverDelegate()).getSysType()<= 20) {
      if (target.getSysType()<= 20 ){
         if (identify.uniform() <= blueProb) {ident= 1;}
         else{ident= 2;}
      }
      else {
         if (identify.uniform() <= redProb) {ident= 2;}
         else{ident =1;}
      }
   }
   else {
      if (target.getSysType()>= 21 ){
         if (identify.uniform() <= redProb) {ident= 1;}
         else{ident =2;}
      }
      else {
         if (identify.uniform() <= blueProb) {ident= 2;}
         else{ident= 1;}
      }
   }
   identification[0] = Math.min(IDlowMag[0],IDhighMag[0]);
   identification[1] = IDlowMag[1];
   identification[2] = ident;
   return identification;
   }
```

```java
public static double[] onlyBCISID(M1BasicMover target, M1BasicSensor
      sensor) {
   double[] identification = new double[3];
   double[] IDlowMag = Acquire.detectLevel(target, sensor,
      sensor.getAtmosCond(), 1, sensor.getIdLevel());
   double[] IDhighMag = Acquire.detectLevel(target, sensor,
      sensor.getAtmosCond(), 2, sensor.getIdLevel());
   double blueProb = ((.95 - getBluePer())/3)*(sensor.getIdNum()-
      1)+getBluePer();
   double redProb = ((.95 - getRedPer())/3)*(sensor.getIdNum()-
      1)+getRedPer();
   boolean BCISfail = false;
   double probSent = .996;
   double probReturn = .996;
   double probCorrect = identify.uniform(.925,.97);
   double probMisID = .95;
   double probSysFail = .975;
   double BCISTime = identify.uniform(.92,1.0);
   double prob = probSent*probReturn*probCorrect*probSysFail;
   if(target.getSysType()<=20&&(M1BasicMover)sensor.getMoverDelegate())
            .getSysType() <=20){
      if (identify.uniform() <= prob) {ident= 1;}
      else{
         BCISfail = true;
         if (identify.uniform() <= blueProb) {ident= 1;}
         else{ident= 2;}
      }
   }
   else if(target.getSysType()>=20&&((M1BasicMover)sensor.
      getMoverDelegate()).getSysType() <=20){
      BCISfail = true;
      if (identify.uniform() <= redProb) {ident= 2;}
      else{ident= 1;}
   }
   else if(target.getSysType()>= 20 && ((M1BasicMover)sensor.
      getMoverDelegate()).getSysType() >=20){
      if (identify.uniform() <= prob) {ident= 1;}
```

```
    else{
        BCISfail = true;
        if (identify.uniform() <= redProb) {ident= 1;}
        else{ident= 2;}
    }
}
else {
    BCISfail = true;
    if (identify.uniform() <= blueProb) {ident= 2;}
    else{ident= 1;}
}
if (BCISfail) {
    identification[0] = Math.min(IDlowMag[0],IDhighMag[0]);
}
else {identification[0] = (BCISTime)/60;}
identification[1] = sensor.getIdNum();
identification[2] = ident;
return identification;
}
```

```java
public static double[] fullBCISSA(M1BasicMover target, M1BasicSensor
      sensor) {
   double[] identification = new double[3];
   double[] IDlowMag = Acquire.detectLevel(target, sensor,
      sensor.getAtmosCond(), 1, sensor.getIdLevel());
   double[] IDhighMag = Acquire.detectLevel(target, sensor,
      sensor.getAtmosCond(), 2, sensor.getIdLevel());
   double blueProb = ((.95 - getBluePer())/3)*(sensor.getIdNum()-
      1)+getBluePer();
   double redProb = ((.95 - getRedPer())/3)*(sensor.getIdNum()-
      1)+getRedPer();
   boolean BCISfail = false;
   double probSent = .996;
   double probReturn = .996;
   double probCorrect = identify.uniform(.925,.97);
   double probSysFail = .975;
   double BCISTime = identify.uniform(.92,1.0);
   double probSAmessage = 0.89562051;
   double prob = probSent*probReturn*probCorrect*probSysFail;
   double SAdelayTime = identify.uniform(1.096,1.333);
   double finalSAdelayTime;
   if (target.getSysType()<= 20 && ((M1BasicMover)sensor.
      getMoverDelegate()).getSysType() <=20){
      if (identify.uniform() <= prob) {ident= 1;}
      else{
         BCISfail = true;
         if (identify.uniform() <= blueProb) {ident= 1;}
         else{ident= 2;}
      }
   }
   else if (target.getSysType()>= 20 && ((M1BasicMover) sensor.
      getMoverDelegate()).getSysType() <=20){
      BCISfail = true;
      if (identify.uniform() <= redProb) {ident= 2;}
      else{ident= 1;}
   }
   else if (target.getSysType()>= 20 && ((M1BasicMover) sensor.
```

84

```java
        getMoverDelegate()).getSysType() >=20){
        if (identify.uniform() <= prob) {ident= 1;}
        else{
            BCISfail = true;
            if (identify.uniform() <= redProb) {ident= 1;}
            else{ident= 2;}
        }
    }
    else {
        BCISfail = true;
        if (identify.uniform() <= blueProb) {ident= 2;}
        else{ident= 1;}
    }
    int numTry = 0;
    while (identify.uniform() > probSAmessage){numTry++; }
    finalSAdelayTime = BCISTime +SAdelayTime+SAdelayTime*numTry;
    if (!BCISfail){
        if (ident==1){
            sensor.waitDelay("SAFriendUpdate",Math.max(0.0,
                (finalSAdelayTime/60 + identify.boxMuller(14.03/60,
                4.068/60))), target);
        }
        else {
            sensor.waitDelay("SAFoeUpdate", Math.max(0.0,
                (finalSAdelayTime/60 + identify.boxMuller(14.03/60,
                4.068/60))), target);
        }
    }
    if (BCISfail) {
        identification[0] = Math.max(0.0,Math.min(
                IDlowMag[0],IDhighMag[0]));
    }
    else {identification[0] = (BCISTime)/60;}
    identification[1] = sensor.getIdNum();
    identification[2] = ident;
    return identification;
}
```

85

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